Impact of phosphorus fertilization strategies on efficiency of nitrogen use by corn rotated with soybean

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Introduction

Management of nitrogen (N) and phosphorus (P) can represent a significant input cost for corn and soybean production. Optimum management of N and P is key in minimizing costs and maximizing productivity. New recommendations for nitrogen management reflect both fertilizer cost and crop price in calculating nitrogen needs. The new recommendations give rates that are intended to apply N to the point where a $1 invested in fertilizer will return a dollar in crop value and to identify the point where the Maximum Return to N (MRTN) is achieved. Since both N and P are needed in significant quantities to maximize yield, the effect of how one is managed on the other cannot be ignored. Phosphorus recommendations do not factor in fertilizer price and focus on application of fertilizer in soil test ranges that are highly responsive to applied P, or building to levels that maximize yield and profit potential. Since soil types and chemical properties can vary widely across a field a single one type fits all management strategy may not fit within a field.

Phosphorus recommendations are based on either a sufficiency level concept or a build and maintenance program. The sufficiency level concept (SLAN) utilizes soil testing to determine the amount of fertilizer needed to maximize crop yield, while the build and maintenance (BPM) strategy builds the soil to a certain level then applies a maintenance rate to keep the soil at that target level. Current University of Minnesota recommendations are based on the SLAN approach. The question is should farmers be targeting specific soil test levels rather than fertilizing based on need, and depending on what is used is there an effect on optimum nitrogen rates? Also, should these decisions change based on soil type, chemical properties or landscape position? In particular, soils in western Minnesota can contain high amounts of calcium which can form insoluble calcium phosphates and tie up fertilizer P. Under these circumstances it can be difficult to build soil P levels therefore aggressive build and maintenance P fertilization may not be feasible.

The following is a final summary of the project data. Objectives of this project were to:

1. Compare crop response to P management systems based upon SLAN versus BPM concepts.

2. Study how soil properties across a landscape may interact with P management strategies.

3. Evaluate how P management systems may affect N fertilizer use by corn rotated with soybean.

Field Trial Design

A single field trial was established in Cottonwood County south of Lamberton. An area 675 feet wide x 1040 feet long was divided into 24 equally sized (225 feet wide x 120 feet long) grid cells. An extra 40 feet was added to both ends of the trial to allow some distance to start and stop the fertilizer applicator at the end of each strip. Prior to fertilizer application, each grid cell was sampled by taking multiple cores from around the center of each area. Initial samples were used to determine phosphorus fertilizer rates. Phosphorus was applied for a two year corn-soybean rotation to 75 feet wide strips. For the SLAN recommendations, fertilizer P was applied based on University of Minnesota recommendations for 180 bu./ac. corn and 50 bu./ac. soybeans. In the BPM recommendation fertilizer P was applied for P removed for the specified yield goals plus enough fertilizer to raise the soil test by 5 ppm (18 lbs P_2O_5/ppm). The goal of this strategy is to raise soil P to the High level and maintain, which should represent a low risk for potential yield loss.

Table 1. Phosphorus application rates by Olsen soil test P classification

	P Rate Applied Based on Olsen Soil Test Class				
	Very Low	Low	Medium	High	Very High
P Strategy	0-3ppm	4-7	8-11	12-15	16+
	-----------------------------lbs. P_2O_5/ac----------------------------				
No P	0	0	0	0	0
SLAN	200	145	45	15	0
BPM	210	210	120	120	120

A summary of rates of P applied for each soil test classification is given in Table 1. Rates averaged 105 and 175 lbs P_2O_5 applied across the entire trial area for the SLAN and BPM strategies, respectively in 2008 and 123 and 158 lbs P_2O_5 applied in 2010. Specific applications rates were 210 lb P_2O_5 BPM and 145 lb P_2O_5 SLAN for Low soil tests, 120 lb P_2O_5 BPM and 45 lb P_2O_5 SLAN for Medium soil tests, and 120 lb P_2O_5 BPM and 15 lb P_2O_5 SLAN for High soil tests (Table 1). Rates in 2008 were based solely on the grid cell center sampling prior to trial initiation. In 2010, P was reapplied based on soil tests taken from individual P treatments. Thus, all P was applied the first year assuming a constant soil test P level within each grid cell while rates were adjusted within each grid cell area in 2010 to account for build or decline of P from P application according to the individual P strategy. Di-ammonium phosphate (DAP, 18-46-0) was applied to all strips except for when the N rate applied with DAP exceeded rates for the N treatments (0 and 50 lb N rate). In the case of low N rates triple-superphosphate (0-46-0) was used. Five nitrogen rates were superimposed as 15 feet wide strips on each P management strip and arranged randomly. Urea was broadcast at rates to achieve rates of 0, 50, 100, 150, and 200 lbs N/ac. Both N and P fertilizer was broadcast and incorporated prior to planting corn.

The location was planted May 20, 2008 with Dekalb 52-59 at 35,200 plants per acre. Planting data from 2009 and 2010 were unavailable. However a single hybrid and variety were used within the trial for both years. Small plant samples were taken at the V5 growth stage from all P management x N rate combinations for corn and only the 0 and 150 lbs N rates from all P management strips in soybean. Plant samples were dried and weighed to determine above ground biomass and were analyzed for total nitrogen (on corn only) and phosphorus. Grain yield measurements were determined by harvesting the middle 30-60 feet from each N strip within each grid cell with a research grade combine. The combine measured grain weight and moisture simultaneously. Yields were calculated and adjusted to 15.5% moisture for corn and 13% for soybean. A subsample of grain was saved from each yield measurement area. Grain was dried, ground in a flour mill, and submitted to the lab for P analysis to determine P removal. Grain P removal numbers are reported in lbs. of P_2O_5 removed per acre.

Statistical analysis was conducted using SAS. Analysis of variance procedures were used to assess the effects of the main plots (P fertilization strategy), sub-plots (N rate), and their interaction. When analysis indicated a significant effect of N rate regression analysis was used to determine the relationship between the measured variable and N rate. The study area was divided into soil classification areas (Low, Medium, and High) based on initial soil samples to study the effect of P and N management on various starting soil test P values.

Results and Discussion

Soil test Data Summary

Grid cells were entered in a GIS software package to delineate soil map units. Three distinct soil map units, Letri, Dickman, and Jeffers, were identified at this location (Figure 1). The majority of the grid cell areas tested Low in soil P according to the Olsen P test (Figure 2). For the most part the low soil test areas were confined to the depressional areas within the fields, medium tests were on side-hills and the high testing areas were on the summit positions. The Bray P test was run on all samples and used as a comparison if soils were close to the break between two classes. Utilizing these comparisons 16 grid cells were determined as Low, 4 as medium, 2 High, and 1 each as Very Low and Very High. For analysis purposes the Very High and Very Low cells were averaged with the High and Low grid cells, respectively. Low testing areas were likely due to high soil pH values in the same locations (Figure 3) which represent high potentials for P fixing. The goal of this study was to build areas within the field, therefore an evaluation of soil test following corn and soybeans will show how successful the build rates were at increasing soil test P. Actual build rates may be slower on some of these high pH soils so it needs to be established if a build program is feasible in such areas. An analysis of soil sample data indicated that the U of M (SLAN) recommendations in the High P management areas actually tested low so a direct comparison between the three management strategies is not possible at this time, thus comparisons between management strategies will only be made for the No P and BPM strategies in the High soil test areas. A summary of soil K is given in Figure 4, although broadcast K was applied before planting at a non-limiting rate for both crops.

A summary of the number of grid cells testing Low, Medium, or High is given in Table 2 for the Bray-P1 and Olsen P tests. Interpretations of both tests resulted in differences in the number of grid cell areas testing in the Low or Medium category. For the Olsen test approximately ¾ of the area tested low while only about ½ of the area was low according to the Bray-P1 test. Because of this both tests were used in the initial determination of application rates, especially when results were borderline between two soil test categories. In general the Olsen test was used to make recommendations since soil pH levels were at or above that which the Bray-P1 test is recommended to be used. In general the Bray-P1 test will underestimate the amount of P in the presence of high amounts of calcium carbonate in high pH soils. The Olsen P test is better used in soils where carbonate is present and can also be used with low soil pH values and would be better used in assessing soil P status in the area studied.

Table 2. Number of grid cells falling in the Low, Medium, and High soil test classification for the Bray-P1 and Olsen P tests before and after the first P fertilizer application.

		Number of Cells‡					
		Bray-P1			Olsen		
Year	P Strat†	Low	Med.	High	Low	Med.	High
		<11 ppm	11-15	>15 ppm	<8 ppm	8-11	>11 ppm
2008		13	8	3	17	5	2
2010	No P	22	0	2	22	1	1
	SLAN	14	8	2	18	6	0
	BPM	5	9	10	9	11	4

† Number of grid cells testing low, medium, or high according to the Bray-P1 and Olsen P tests (n=24)
‡ P strategy applied after 2008 initial soil test

Table 3. Statistical summary of change in Olsen P from Initial soil test values for each P strategy, two nitrogen rates (0 and 150 lbs), and their interaction.

		Statistics§			Olsen P Change†		
	Class‡	P Strat.	N Rate	P x N	No P	SLAN	BPM
		--------------*P>F*----------------			--------------ppm--------------		
2008	Low	<0.001	0.01	0.05	-2 c	2 b	4 a
	Medium	0.005	0.54	0.87	-3 b	-2 b	3 a
	High	0.06	0.70	0.78	-5	-8	2
2009	Low	<0.001	0.002	0.04	-2 b	1 a	2 a
	Medium	0.009	0.47	0.78	-3 b	-4 b	3 a
	High	0.44	0.43	0.74	-5	-8	-2
2010	Low	<0.001	0.78	0.005	0 c	4 b	11 a
	Medium	<0.001	0.57	0.07	-4 b	1 b	6 a
	High	0.005	0.42	0.85	-4 b	-3 b	9 a

† Change from initial Olsen P for each P strategy. Letters following numbers represent least significant difference ($P \leq 0.05$) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at $P \leq 0.05$.

Data in Table 3 and Figure 5 summarizes soil test change following the three cropping years studied. Over all years soil P increase was significantly ($P \leq 0.05$) influenced by P strategy. This was true when initial soil P class was considered, except for the initial high testing areas. In this case soil P was only affected following the second P application before the 2010 crop where the BPM treatment tended to increase soil P even though the rate applied was meant to maintain. When soils initially tested in the Medium classification the BPM strategy tended to increase soil P while the SLAN strategy either maintained or slightly lowered STP and there were no differences between the SLAN or No P treatments. When soils initially tested low both P strategies increased soil P over the control but the BPM tended to increase more than the SLAN. This is not surprising based on the difference between application rates of the two strategies. The surprising result was that soil P could be influenced in the Low areas since there were dominated with high pH soils which may have had a tendency to fix P making it unavailable for the next years' crop. The increases indicate that soil P can be built in the particular soils at this location. Therefore high pH may not mean that soils could not be built. The main factors that are important are potential for crop yield increase and profit per acre from the P application.

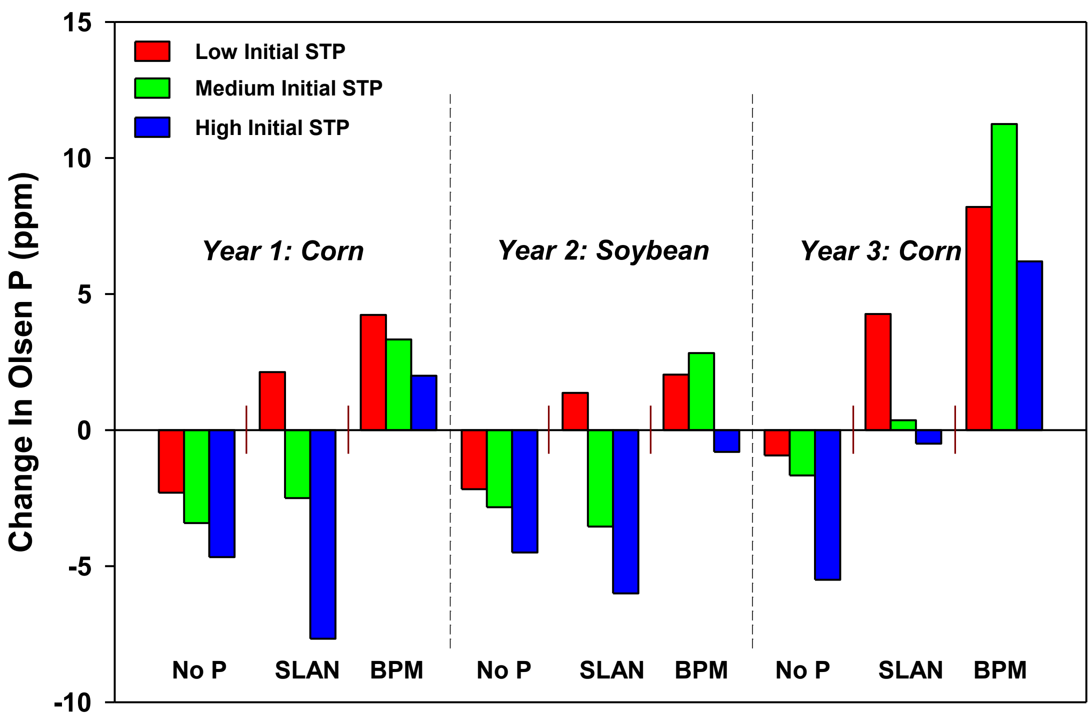

Figure 5. Summary of change in Olsen phosphorus level after 1, 2, and 3 cropping years. Fertilizer was applied to SLAN and BPM treatments prior to years 1 and 3.

After each crop soil samples were collected from the 0 and 150 N rate plots for each P strategy within each grid cell area. This was done to study if soil test P change was affected based on initial soil test classification and yield differential between the 0 and 150 lb N plots. Since P removal in grain is largely influenced by yield, lower yield due to deficient N could lead to a faster buildup of soil P. The effect of nitrogen rate was only significant for field areas initially testing Low in P. Further study of the data showed that while N rate did significantly influence soil P change the effects seemed to be limited to the treatments where P was applied (BPM and SLAN). This effect is indicated by the significant interaction between P and N. In both P strategies soil P was increased faster when N was not applied. This provides evidence that P may not have been efficiently utilized when N was limiting which left more P to carryover to another crop or potentially form low solubility compounds with calcium in high pH soils. This indicates that 1) N should be applied at recommended rates to increase utilization of applied P; 2) any P not used by the first year crop may be carried over; and 3) soil P change can be greatly affected by P application rate even in high pH soils.

Effects on early plant growth, nitrogen, and phosphorus uptake

Table 4. Summary of Plant weight and N and P uptake data for corn in 2008 broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

		Statistics§			Plant Weight, N, and P Uptake†					
Class‡		P Strat.	N Rate	P x N	No P		SLAN		BPM	
Plant Weight		--------------*P>F*----------------			--------------g/plant--------------					
	Low	<0.001	0.73	0.63	3.9	b	5.2	a	5.7	a
	Medium	<0.001	0.01	0.60	5.0	b	5.1	b	6.6	a
	High	<0.001	0.41	0.82	5.5	b	3.5	c	7.7	a
N Uptake					--------------mg/plant--------------					
	Low	<0.001	0.02	0.77	157.0	b	228.9	a	232.3	a
	Medium	<0.001	<0.001	0.60	205.7	b	214.3	b	266.3	a
	High	<0.001	0.02	0.77	228.2	b	142.6	c	320.8	a
P uptake					--------------mg/plant--------------					
	Low	<0.001	0.61	0.88	13.5	b	22.2	a	21.9	a
	Medium	<0.001	0.12	0.76	19.3	b	20.0	b	27.6	a
	High	<0.001	0.40	0.68	22.0	b	13.0	c	31.9	a

† Letters following numbers represent least significant difference (P≤0.05) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at P≤0.05.

Early growth and nutrient uptake data were summarized by initial soil P classifications and across the trial area. Corn data from 2008 is given in Table 4 and Table 5 contains data from 2010. Early corn growth data is summarized in Figures 6 and 7 for 2008 and 2010 data, respectively. Across the trial early corn plant weight was significantly ($P \leq 0.05$) influenced by both P and N application. In general corn growth responded to the amount of P applied because growth generally differed between the SLAN and BPM strategies. In low testing areas little difference was seen between the SLAN and BPM strategies. However, P application rates were far higher for the SLAN strategy whens soils tested Low (Tables 4 and 5) both years. When soils tested medium there was little difference between the control and SLAN management in 2008 while the BPM consistently had higher plant weights than either treatment both years. For high testing areas the SLAN treatment produced the smallest plant weights in 2008. However, this was not due to a lower application rate of P rather it was due to soil P levels dropping off from the High to Low in the strip areas containing the SLAN treatments. This decrease was not assessed with the initial soil sampling and demonstrates how variable soil P can be over short distances. In this case P was under applied in 2008 while we applied an higher amount according to current recommendations in 2010. There was no difference between the SLAN and BPM strategies in 2010 which demonstrates that the deficiency was likely corrected in the low testing areas.

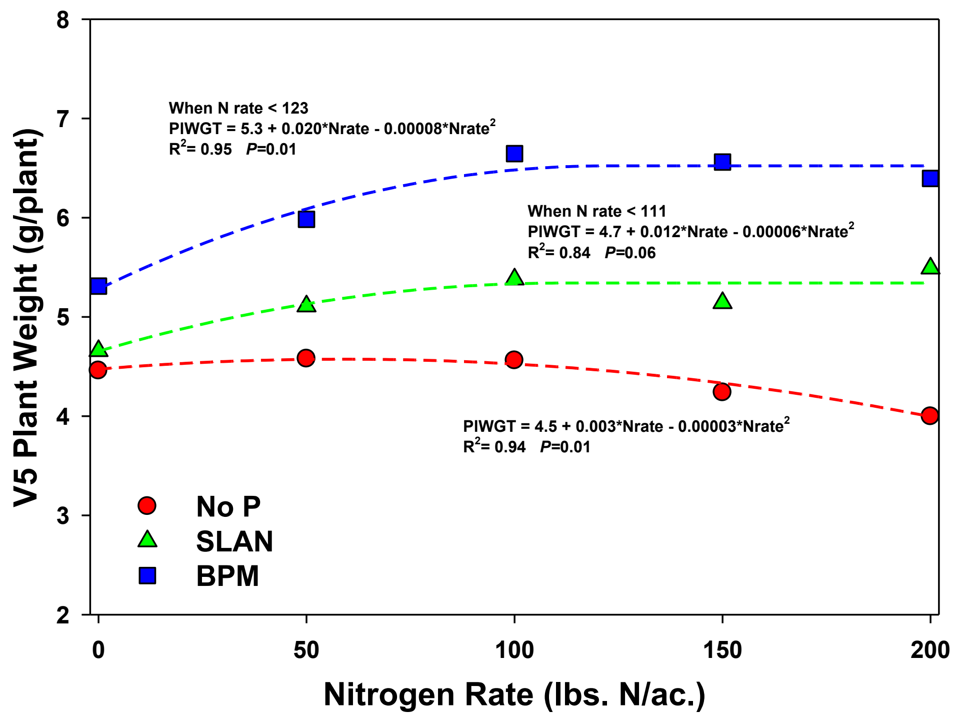

Figure 6. Corn plant weight response at V5 to P fertilizer and N rates for 2008 corn data. Statistics included are for the best fit model for treatment means across all initial P management zones.

In general, plant mass increased as nitrogen rate increased (Figures 6 and 7). It is hard to determine if the differences were an actual growth promotion or growth was limited by lack of N at the low application rates. In most cases growth increased to a maximum with N application. The only exception was for No P plots in 2008 where growth increased to around the 50 lb. rate then unexpectedly decreased. In 2008 growth was maximized with about 120 lbs. of N for both P strategies while a higher rate of nearly 170 lbs. was needed in 2010. In 2010 growth was maximized with less than 100 lbs. when no P was applied. As N become limiting the differences between P management strategies was less noticeable. This indicates that N deficiency can mask some of the potential benefits in early growth from P application. The lower plateau value for both 2008 and 2010 for No P strips also indicates that P may play an important role in the efficiency of N use in corn. By cutting back on P fertilizer a farmer may actually increase the likelihood of N loss if yield and N uptake may be limited. Studies have noted though that increased early plant growth does not necessarily translate into increased yield.

Therefore, effects on yield are more important in making the determination of how much P should be applied.

Table 5. Summary of Plant weight and N and P uptake data for corn in 2010 broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

	Statistics§			Plant Weight, N, and P Uptake†					
Class‡	P Strat.	N Rate	P x N	No P		SLAN		BPM	
Plant Weight	--------------*P>F*---------------			-------------g/plant-------------					
Low	<0.001	<0.001	0.04	1.5	b	2.0	a	2.0	a
Medium	<0.001	<0.001	0.48	1.5	c	1.9	b	2.1	a
High	<0.001	0.14	0.70	1.5	b	1.7	b	2.1	a
N Uptake				-------------mg/plant-------------					
Low	<0.001	<0.001	0.02	63.9	b	87.2	a	87.3	a
Medium	<0.001	<0.001	0.48	67.0	b	87.1	a	94.3	a
High	<0.001	0.06	0.50	67.4	b	72.9	b	97.8	a
P uptake				-------------mg/plant-------------					
Low	<0.001	<0.001	0.07	5.3	b	8.6	a	8.6	a
Medium	<0.001	0.002	0.60	6.0	c	8.5	b	10.4	a
High	<0.001	0.27	0.43	6.6	b	7.5	b	9.6	a

† Letters following numbers represent least significant difference ($P\leq0.05$) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at $P\leq0.05$.

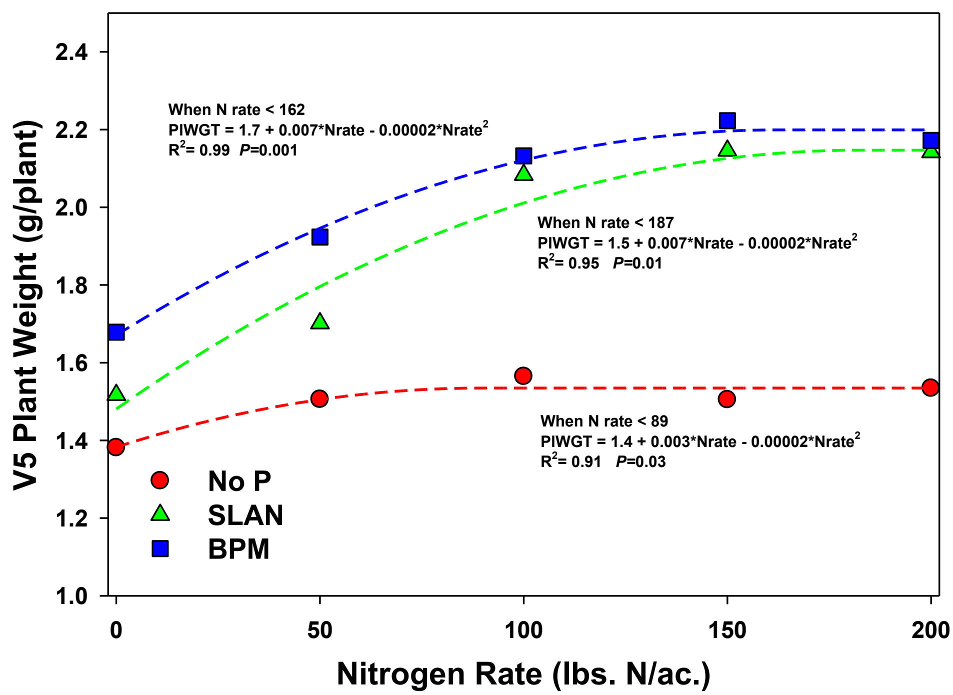

Figure 7. Corn plant weight response at V5 to P fertilizer and N rates for 2010 corn data. Statistics included are for the best fit model for treatment means across all initial P management zones.

Soybean growth was measured at the V5 growth stage from plots receiving 0 and 150 lbs. of N within each grid zone and P management strategy. Plant weight data is given in Table 6. Since no P was directly applied to soybean the effects on early growth would be due to P applied the previous year before corn. Early soybean plant weight was significantly different in the Low and High testing areas. Differences in the Low testing areas were likely due to increased soil test P while those in the High testing areas were due to Low testing areas within the grid cell not being addressed with the first soil sampling. For the Low testing areas there was no difference in soybean plant weights between the SLAN and BPM strategies. This was a similar effect that was seen the previous year in early corn weights. The previous year's nitrogen application also affected soybean plant weights for Low testing areas (data not shown). It was found that soil test P trended higher when no N was applied likely due to underutilization of P when yield was limited by N. In general the differences in soil test P were small, but significant, and it is surprising that soybeans expressed this difference in increased growth.

Table 6. Summary of Plant weight and P uptake data for soybean in 2009 broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

		Statistics§			Plant Weight and P Uptake†					
Class‡		P Strat.	N Rate	P x N	No P		SLAN		BPM	
Plant Weight		--------------*P>F*---------------			--------------g/plant--------------					
	Low	0.002	0.004	0.51	2.9	b	3.5	a	3.2	a
	Medium	0.55	0.15	0.66	3.1		3.1		3.4	
	High	0.05	0.22	0.74	3.1	ab	2.7	b	3.5	a
P uptake					--------------mg/plant--------------					
	Low	<0.001	0.2	0.69	6.7	b	10.1	a	9.6	a
	Medium	0.05	0.82	0.7	8.7	ab	8.3	b	10.9	a
	High	0.002	0.94	0.58	9.1	b	6.3	c	10.8	a

† Letters following numbers represent least significant difference (P≤0.05) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at P≤0.05.

Figures 8 and 9 summarize nitrogen uptake data across the entire trials for 2008 and 2010 corn data, respectively. Nitrogen uptake response followed closely to that of early plant growth. The only major difference was the No P treatments in 2008 that showed a slightly lower early growth at high N rates. Early plant N uptake was generally increased when P was applied. In 2008 plant N uptake was maximized by 140 lbs. of N while the number was slightly less at nearly 120 lbs. in 2010. When P was not applied N uptake was maximized by 47 lbs. of N in 2008 and 95 lbs. in 2010. This indicates that N utilization may be significantly affected by P application and application rate. More total N was taken up in the BPM strips relative to both the SLAN and No P strips in 2008 while similar amounts were taken up by the BPM and SLAN strips in 2010. In order to maximize N utilization it appears that applying optimum P rates may be critical.

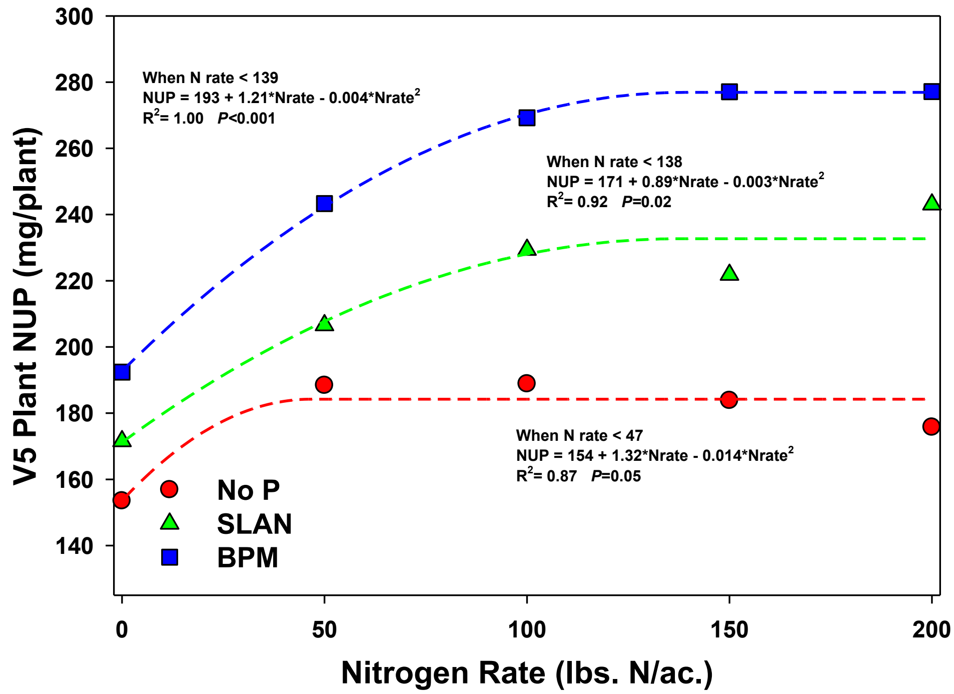

Figure 8. Corn N uptake response at V5 to P fertilizer and N rates for 2008 corn data. Statistics included are for the best fit model for treatment means across all initial P management zones.

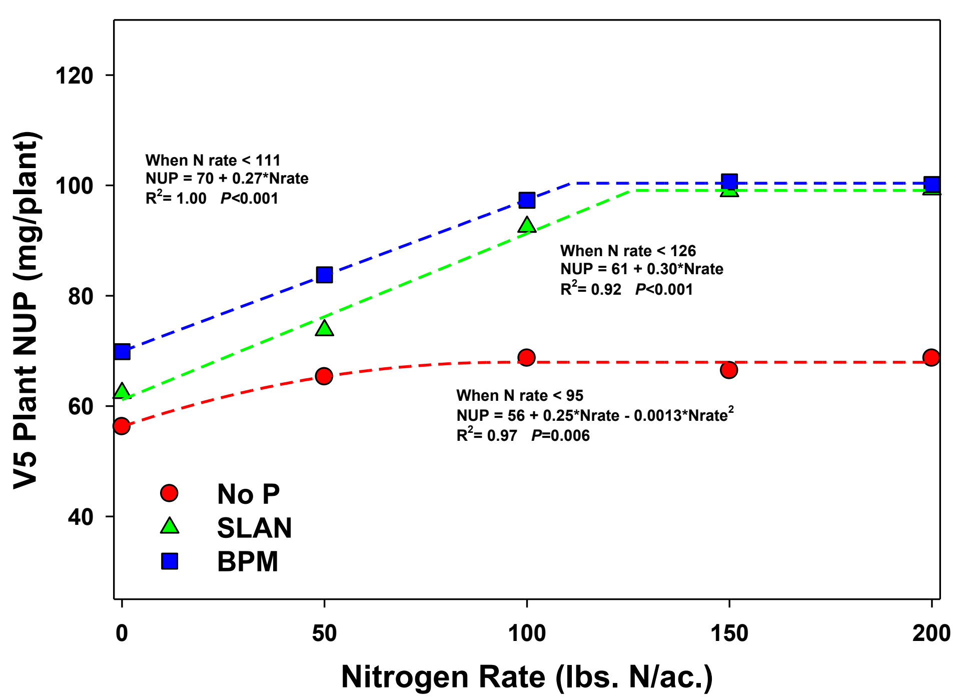

Figure 9. Corn N uptake response at V5 to P fertilizer and N rates for 2010 corn data. Statistics included are for the best fit model for treatment means across all initial P management zones.

Comparisons between initial soil P class and N uptake are given in Tables 4 and 5. In 2008 N uptake was significantly affected by P strategy and N rate regardless of the starting soil test level. In low testing areas both P strategies did not differ in the amount of N taken up, and both were increased relative to No P. However, the P strategies did differ from each other for the Medium and High testing areas. In fact there was no significant difference in N uptake between No P and SLAN treatments in Medium testing areas and N uptake was the lowest with the SLAN treatments in the High testing areas. However, the low N uptake in High soil test areas was due to limited plant growth due to Low testing areas in the grid cells encompassing the SLAN treatment areas as was discussed previously for early growth responses. In 2010, N uptake was significantly affected by P strategy and N rate again across all initial soil test P levels. The significance level of N rate for the High testing areas was borderline at P=0.06 but based on past years data we likely can say that this was a significant effect (accepted level for significant increases is $P \leq 0.05$). Plant N uptake was higher for both P strategies for the Low and Medium soil test areas and there was no difference between either of them. For high testing areas the BPM strategy alone significantly differed from No P. While N uptake early in the growing season may not be fully related back to yield it does give a picture of N utilization efficiency. While we were not at 100% utilization efficiency, the application of P appears to be important at increasing N efficiency especially in Low and Medium testing soils.

Early P uptake was influenced by early plant growth for corn (Tables 4 and 5) and soybean (Table 6). In general, P concentration did not differ between treatments (data not shown) therefore P uptake was related to early plant weights as has been shown in past research. Many research studies have shown the benefit of applying P in a band near the seed at planting on early corn growth. It was somewhat surprising to see the magnitude of growth increases in this study. However, the amount of low testing areas included in the study make large responses for likely. In fact, P uptake was nearly doubled in Low testing areas and increased only 50% in Medium and High testing areas. There was no significant effect of N rate on P uptake in 2008 while there was a small effect of N rate in Low and Medium testing areas in 2010. The reason for the significant effect of N rate is unclear but could be due to residual effects of N, possibly due to nutrient cycling, on the 2010 crop, or could be due to differences in the year or hybrid grown. For soybean, the patters were similar to that of corn. In Low testing areas both P strategies affected P uptake similarly, while the BPM strategy produced greater P uptakes relative to No P in the Medium and High testing areas.

The soybean P uptake data is important because it does show that some P can be carried over to the soybean crop when the P was applied before corn (Table 6). Soil pH levels in the low testing areas were high so some P fixation may be expected. However, it does not appear that in these particular soils that all of the P is fixed therefore P would not necessarily have to be applied before both crops in order to increase yields. Without knowing the effect on yields it cannot be determined what the best management strategy is for P. In Low testing areas some P should be applied in order to potentially maximize yield potential and N uptake efficiency.

Effects on grain yield and P removal in grain

Table 7 Summarizes corn yield and P removal data for the 2008 Yield data by initial soil test P area. Yield was significantly ($P \leq 0.05$) affected by N rate across all P management strategies. When soils tested low the difference was on average 30 bushels from No P with both the SLAN and BPM strategies. For medium testing soils the effect of P did not reach the accepted significance level and could not be determined that P increased yields. For high testing areas there were significant differences between P management strategies. However, the major effect was due to the low yields in the SLAN treatment caused by a large decrease in soil P in those areas of what was identified initially of high testing areas. It is likely that the grid cell center sampling was not sufficient to determine the actual soil test P level average of the grid cell area. In effect this decrease was only due to the soil test difference and not due to a lack of applied P in those field areas. Similar effects were seen for early growth and N and P uptake. Uptake of P in corn grain was influenced by N and P application in all areas of the field. This effect is mainly due to the influence of yield on the removal of P. As yield increased P removal increases therefore, in the case of the BPM strategy, maintenance rates should be adjusted based on long-term yield averages. In this case the yield averages were close to expected yields but soil P tended to still increase.

Table 7. Summary of 2008 corn grain yield (adjusted to 15.5%) and P removal in grain broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

		Statistics§			Grain Yield and P Removal†					
	Class‡	P Strat.	N Rate	P x N	No P		SLAN		BPM	
Yield		--------------*P>F*----------------			--------------bu./ac.--------------					
	Low	<0.001	<0.001	0.77	143	b	172	a	171	a
	Medium	0.17	<0.001	0.3	158		168		172	
	High	0.002	0.02	0.30	166	b	149	b	192	a
P removal in Grain					--------------lb. P_2O_5/ac.--------------					
	Low	<0.001	0.02	0.56	38.5	b	57.9	a	56.8	a
	Medium	<0.001	0.004	0.85	46.7	b	50.8	b	63.2	a
	High	<0.001	0.03	0.07	52.2	b	45.1	b	71.2	a

† Letters following numbers represent least significant difference ($P \leq 0.05$) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at $P \leq 0.05$.

There was no significant interaction between N rate and P management strategy. This indicates no evidence that the optimum nitrogen rate changes based on the rate of P applied. Another question is does the optimum N rate change based on initial soil test P zone? However, there were not enough zones in the High and Medium to make a good comparison to low testing areas. From the P application data and other research it does not appear that N rates should vary whether P is or is not applied. Also, we could not fully tell if apparent yield differences in this study between initial soil P classes were due to the difference in P status of the soil. In this particular study there were differences in drainage that could have influenced overall yield levels in Low and Medium testing areas. Unless a study can be conducted on similar soil conditions, it is hard to tell if Initial P level alone is a major limitation on yield in high pH soils. Further research should be conducted to determine if initial P soil test level is important for high yields or can a low testing soil be fertilized to achieve the same yield level versus if that soil was high testing to start with.

Table 8. Summary of 2009 soybean grain yield (adjusted to 13.0%) and P removal in grain broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

		Statistics§			Grain Yield and P Removal†		
	Class‡	P Strat.	N Rate	P x N	No P	SLAN	BPM
Yield		--------------*P>F*----------------			--------------bu./ac.--------------		
	Low	<0.001	0.24	0.61	41.0 b	61.0 a	61.0 a
	Medium	0.14	0.61	0.89	45.0	56.0	46.0
	High	0.46	0.32	0.32	48.0	47.0	57.0
P removal in Grain					--------------lb. P_2O_5/ac.--------------		
	Low	<0.001	0.01	0.58	28.9 b	55.9 a	55.9 a
	Medium	0.21	0.43	0.82	36.4	45.8	43.5
	High	0.07	0.09	0.54	41.4	36.2	53.8

† Letters following numbers represent least significant difference (P≤0.05) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at P≤0.05.

Fertilizer P was applied for the second year soybean crop with the initial application before the corn. This was done to study the effect of carryover of P from corn to the soybean crop. Past research has shown soybeans to have a lower critical soil test level for P (soil test at which further application of P does not result in greater yields). However, having deficient P can severely limit soybean yields and cut profitability. Data from the 2009 soybean crop (Table 8) indicated that yield could be increased with the application of P before the corn crop. However, yield was only increased when the soils tested Low before the corn. The yield increase from both P management strategies was 20 bu/ac for the 2-year application and there were no differences between the more conservative SLAN strategy and aggressive BPM strategy. The BPM did result in a larger increase in soil P prior to soybeans than the SLAN. However, it does not appear that this had a major impact on yield. It appears that soybean yield can be maximized as long as application rates before the corn also account for the next year's soybean crop. What is not known is whether a field with a potential higher fixing potential may warrant separate applications for both crops? In the case of this soil there was no evidence that single year applications of P should be made in order to increase yield.

Phosphorus removal in gran was only affected by P strategy or N rate in the Low testing areas of the field. When P was applied there was a large increase in the amount of P removed in grain similar to large increases in yield. Similar to the 2008 corn P removal in grain was highly related to grain yield. The effect of N rate was likely due to higher removal when no N was applied due to a slightly higher soil test P level. As was previously discussed, high soil P when no N was applied may be due to lower P removal due to a lower yield in the 0 N plots. When P is applied soil tests need to be monitored, this is especially true with the SLAN treatment where P was applied at less than crop removal in the Medium and High soil test areas of the field. In general soil test values do not drop quickly, but monitoring on a consistent basis will insure that areas of the field are fertilized properly.

Table 9. Summary of 2010 corn grain yield (adjusted to 15.5%) and P removal in grain broken down by Low, Medium, and High soil test areas and statistical analysis for main treatment effects and their interaction.

		Statistics§			Grain Yield and P Removal†					
	Class‡	P Strat.	N Rate	P x N	No P		SLAN		BPM	
Yield		--------------*P>F*----------------			--------------bu./ac.--------------					
	Low	<0.001	<0.001	0.01	147	b	174	a	180	a
	Medium	0.003	<0.001	0.27	153	b	177	a	170	a
	High	<0.001	<0.001	0.009	158	b	163	b	207	a
P removal in Grain					--------------lb. P_2O_5/ac.--------------					
	Low	<0.001	<0.001	0.002	52.7	b	79.9	a	84.0	a
	Medium	<0.001	<0.001	0.50	58.4	b	77.4	a	80.2	a
	High	<0.001	<0.001	0.06	62.1	c	72.1	b	98.0	a

† Letters following numbers represent least significant difference ($P \leq 0.05$) within each row.
‡ Initial soil P classification before treatment application for grid cell areas.
§ ANOVA for P strategy, Nitrogen Rate, and their interaction (P x N). Effects are considered significant at $P \leq 0.05$.

A second two year P application was made following the second year soybeans for a third year corn crop. This application was varied based on soil test increase or decrease from the initial application. Therefore, grain yields would have been influenced by residual P left from the 2008 application and newly applied P. Table 9 summarizes the third year corn data for yield and P removal in grain based on soil test areas defined by the initial soil sampling (the same used for 2008 yield data in Table 7). Yield was significantly affected by P strategy and N rate for all soil P classes. For the soil areas testing low in 2008 there still was no yield difference between the SLAN and BPM strategies. Data in Table 3 does show that both the SLAN and BPM strategies increased soil P by 1-2 ppm prior to the last P application. Therefore, there appeared to be no clear benefit in the larger application rate for the Low testing soils to rapidly increase soil P. The SLAN treatment did include some extra P to build the soil test and it appeared that alone was enough. For medium testing cells there again was no difference between yield increases for both the SLAN and BPM strategies. However, soil appeared to decrease slightly (Table 3) prior to the third year corn. For High testing areas the BPM strategy produced greater yields than No P and the SLAN. The areas for the SLAN treatment in those cells were found to be low testing following the first cropping year. The P rate applied was increased to those areas but yields still may have suffered due to drainage or other differences in soil properties. This area also only included 3 areas of the trial so data was limited. There was some evidence of possible differences in N requirement for the different P strategies for the Low and High testing areas. However, there was no clear pattern in the data even though across the entire trial area there did appear to be a trend for less N required when No P was applied which may have been due to limited yield.

Phosphorus removal in grain trended to follow similar patterns as grain yield. Application of P always resulted in greater removal of P and rate did not appear to differ. The only exception was in the High testing areas where the SLAN and BPM both resulted in greater P removal and both differed from each other. In 2010 P removal did appear to be greater which may have been due to different hybrids used from 2008 to 2010.

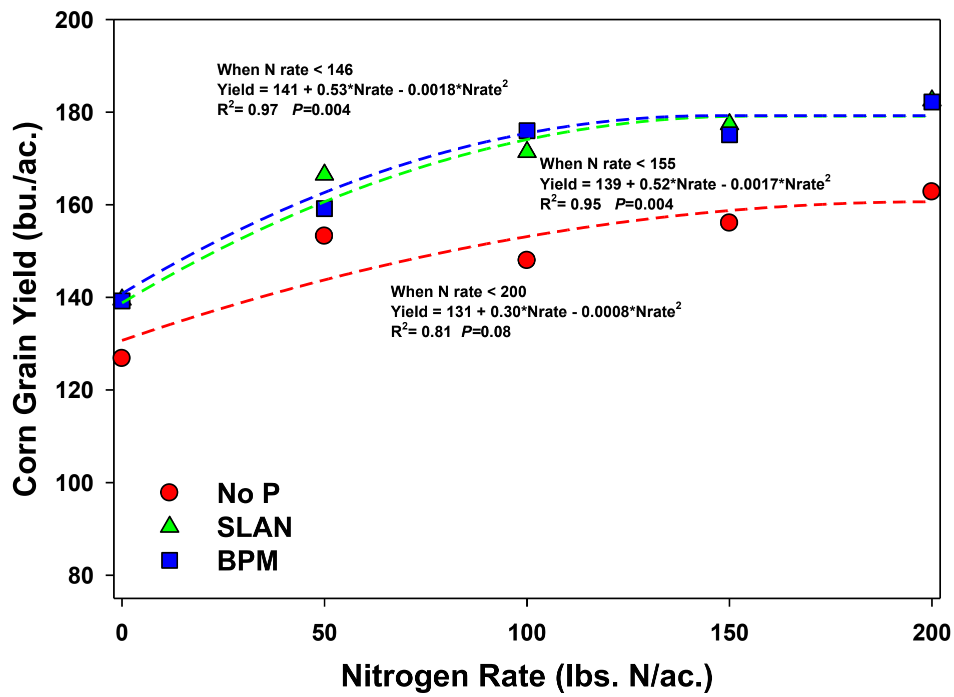

Figure 10. Summary of corn grain yield (adjusted to 15.5% moisture) response to N in 2008. Statistics included are for the best fit model for treatment means across all initial P management zones.

Figure 10 and 11 summarize N rate response across the trial areas for each P management strategy for 2008 and 2010 data, respectively. In 2008, yield increase due to N rate was similar across all P management strategies. Agronomic yield maximized at approximately the same rate of N, 150 lbs, for both P management strategies and appeared to not maximize at all at 200 lbs for the No P treatment. However, the statistical analysis did not provide evidence that there was any significant interaction between N rate and P management strategy and therefore no evidence of a difference in the amount of N needed based on P management. A similar pattern was seen in 2010 which no clear differences in the N need based on P management even though it appeared that less N was needed when No P was applied. Overall it does not appear that different N rates should be recommended based on how P fertilizer is managed. Early season N uptake data would suggest some differences in N utilization, but these were not translated into yield. However, the main difference both years appeared to be increased yield potential from P, thus P management is important in making sure there is a high potential for profit.

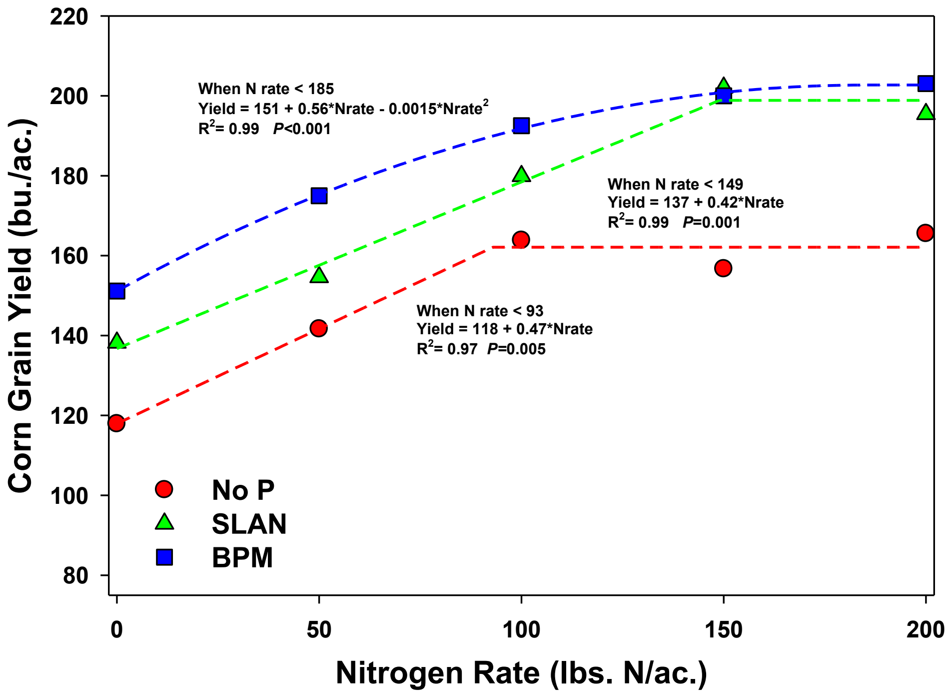

Figure 11. Summary of corn grain yield (adjusted to 15.5% moisture) response to N in 2010. Statistics included are for the best fit model for treatment means across all initial P management zones.

A study was made of the net P applied (P applied in fertilizer minus P removed in grain) for all years of the study with change in Olsen soil test P (Figure 12). Soil P change was significantly related to net additions of P following both corn years of the study (Years 1 and 3). Following soybean the soil test change was not significantly impacted by net additions of P. As was stated most of the area of this study was Low in soil P and had pH levels testing 7.4 or higher. We would therefore expect some P fixation. Following corn, the graphs showed clusters of data points that were related to the P treatments in the study. The BPM resulted in the largest increases on average in soil P which was not surprising since the net amounts of P applied were the greatest with these treatments. The next highest treatment was the SLAN which resulted in smaller but mainly positive increases in soil P. The No P treatments generally resulted in a decrease in soil P from the initial values.

The linear relationship after corn provide more evidence that some P will carry over to the following years crop in-spite of the high soil pH levels at this site. After corn, when net P additions were 0 (P removed = P applied) the net change was slightly negative in 2008 (-1.4 ppm) and slightly positive in 2009 (2.9 ppm). It is unclear if these changes are a result of P cycling or random variability. As was noted, when removal rates were applied soil P tended to increase. This indicates that not all of the applied P for the removal rates likely was used and what was not used lead to a buildup of soil P (Figure 5). This buildup of soil P can potentially be important especially if P fertilizer prices fluctuate greatly from one year to the next. If soils are built up into the high classification, the probability of losing yield from not applying P is small, thus building soil P with low priced inputs may help in years when prices are high. In this study we looked at whether P can be banked for multiple years on a variable landscape. For the most part P did carry over from corn to soybeans giving increased yields the second year. However, soil test P increase was less predictable after soybean therefore some considerations may have to be made as to the appropriate rate of fertilizer on high pH, low P soils to maximize return to fertilizer P.

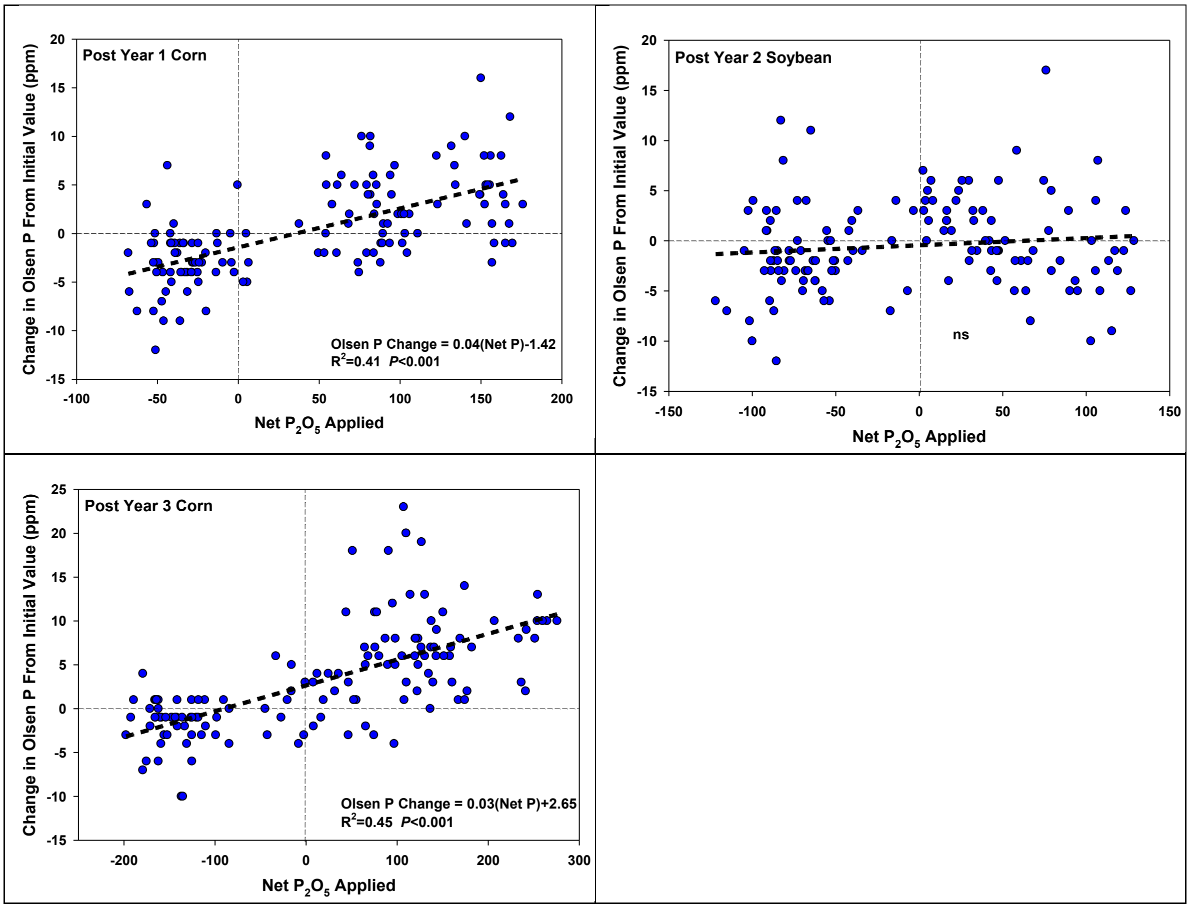

Figure 12. Summary of net P applied (P applied in fertilizer – P removed in grain) versus change in Olsen soil test P following the 3 cropping years studied. Dashed line indicates the best fit, linear, regression model.

Economic Evaluation of N and P Fertilization

Economic evaluations were conducted on yield to determine the net response to P and the N rate that produced the Maximum Return To N (MRTN). The MRTN is a concept that takes into account the price of nitrogen (per lb.) and price of corn to determine the most profitable N rate that returns $1 in crop value for the last $1 invested in fertilizer N. This is different than the plateau nitrogen rates in Figures 8 and 10 and 11. In general, N rates recommended using the MRTN will produce yield potentials less than but very near maximum. Table 10 summarizes MRTN values for the 2008 and 2010 corn data for price ratios ranging from 0.05 to 0.10 for the data presented in Figures 10 and 11.

Recommended N decreases significantly when the cost of N increases relative to crop value. In most cases the price ratio will fall some place between 0.10 and 0.15. For the 0.10 price ratio the amount of N needed was near 120 lbs. of N for corn following soybean in 2008 and was slightly higher in 2010. The increased N need in 2010 may be reflective of the fall application of N before the 2010 crop or increased loss. In general it took about 30 lbs. more N in 2010. Even though the treatments numerically are not the same there was no statistical evidence of a significant ($P \leq 0.05$) difference in the N need between the P management strategies in 2008 and some evidence that the No P strips may have needed less N in 2010.

Table 10. Summary of recommended N application rates from MRTN values for various price ratios based on N rate response data from the different P strategies from 2008 and 2010 data.

		Price Ratio (Price N/Value of Corn)				
Year	P Strat.	0.05	0.10	0.15	0.20	0.25
		---------------------------------lbs N/ac.-------------------------------				
2008	No P	167	133	100	66	33
	SLAN	140	125	110	95	80
	BPM	132	118	104	90	77
2010	No P	93	93	93	93	93
	SLAN	149	149	149	149	149
	BPM	168	152	135	119	102

Table 11. Comparison of recommended N application rates form MRTN values based on the different P strategies broken down into the three initial soil P classifications in the study from the 2008 and 2010 growing season at the 0.10 price ratio.

		Initial Soil Test P Class†		
Year	P strat	Low	Medium	High
		---------------lbN/ac---------------		
2008	No P	67	33	102
	SLAN	139	114	309*
	BPM	134	100	195
2010	No P	100	86	124
	SLAN	294*	239*	107
	BPM	58	206*	215*

† *, denotes where EONR was above the highest applied N rate

Table 11 summarizes the data for each P strategy within the different field areas with similar starting soil P levels. For this comparison MRTN values were determined for the 0.10 price ratio. The 2008 data showed little difference between the SLAN and BPM strategies when compared within initial soil P classification levels. The only apparent difference was for the SLAN treatment in the High testing areas. However, these only included 3 grid cells from the 24 thus there was not as robust a data set to determine optimum N rates in these field areas. Due to this it cannot be determined if there was an actual difference in those areas. When P was not applied the recommended N tended to be less regardless of the starting soil P level. Data from 2010 was more variable with many of the MRTN values occurring above the highest N rate. We therefore cannot fully conclude that optimum N rate does change based on soil P level and P fertilizer application, especially when various P rates are being applied. Again, the data may point to less N required when P is not applied due to a lower yield potential. However, the large increases in yield do not support no application of P in the Low and Medium testing areas of the field.

Table 12. Three year net return of fertilizer P for the SLAN and BPM fertilization strategies over the non-fertilized control for treatments receiving 150 lb. N/ac assuming $5/bu. corn price, $10/bu. soybean price, P fertilizer cost of $0.50/ lb. P_2O_5, and 2/3 of the fertilizer applied for corn and 1/3 for soybeans.

		Net Return to P†			
P Class.	P Strat	Year 1	Year 2	Year 3	Total
		----------------------$/ac.----------------------			
Low	SLAN	$125	$175	$205	$505
	BPM	$105	$165	$186	$456
Med	SLAN	$65	-$8	$139	$197
	BPM	$40	-$20	$130	$150
High	SLAN	-$3	-$2	$49	$44
	BPM	-$40	-$20	$125	$65

† Net return to P based on the difference between each P strategy and the control.

Table 13. Three year net return of fertilizer P for the SLAN and BPM fertilization strategies over the non-fertilized control for treatments receiving 150 lb. N/ac assuming $5/bu. corn price, $10/bu. soybean price, P fertilizer cost of $1.00/ lb. P_2O_5, and 2/3 of the fertilizer applied for corn and 1/3 for soybeans.

		Net Return to P†			
P Class.	P Strat	Year 1	Year 2	Year 3	Total
		----------------------$/ac.----------------------			
Low	SLAN	$75	$150	$170	$395
	BPM	$35	$130	$132	$297
Med	SLAN	$50	-$15	$93	$128
	BPM	$0	-$40	$75	$35
High	SLAN	-$7	-$3	-$11	-$21
	BPM	-$80	-$40	$85	-$35

† Net return to P based on the difference between each P strategy and the control.

Tables 12 and 13 summarize net return to fertilizer P for the SLAN and BPM strategies comparing two scenarios, $0.50 per lb. P_2O_5 (Table 12) and $1.00 per lb. P_2O_5 (Table 13). The 150 lb N rates were only used since these were one of the only rate strips harvested all three years of the study. Net return to P was greatest for the Low testing areas for both P price scenarios in spite of the recommended application rates being the highest in these areas of the field. Net returns were still positive for Medium testing areas for both P strategies although return was greater for the SLAN than the BPM for both Low and Medium testing areas due to the lower application rates. When soils tested High net returns were slightly positive with the lower P price and slightly negative with the higher. For the most part the high testing areas appear to be the most sensitive to price fluctuations and where decisions should be made whether to apply P. The high profit potentials in the Low testing areas warrant application every year even in spite of high prices. Decisions can be more complicated in the medium testing areas, but in general P should be applied. The major issue that was seen in this particular study was that there were some decreases in soil P over the first two years in the medium testing area when the SLAN strategy was used. If the decrease resulted in a drop from the Medium to Low category some yield reductions could be expected if a low fertilizer rate is applied. Therefore, more frequent soil testing may be needed with the SLAN to insure that the correct amount of P is applied. Maintenance applications such as those with BPM do offer some insurance that maximum yield potential can be achieved but risk some potential economic loss with the over application of P. Since both management strategies produced positive economic benefits either could be used effectively and the major decision should involve whether the potential increase in soil P would be beneficial to the grower. Some P banked in the soil may be available for multiple years and in the case of land ownership or long-term leases any P carried over may be used following years. In the case of short-term land tenure there may be no benefit to rapid buildup in soil P and the higher return of the SLAN strategy may be better, especially in Low testing areas within the field. This shows that there is flexibility in how P can be managed even in fields with variable soil properties.

Conclusions

Application of P fertilizer before corn for a 2 year corn-soybean rotation significantly increased yields when soil tested Low to Medium. In areas testing High there was little to no benefit from P application. Soil chemical properties were related to landscape position within the field. Application of P fertilizer affected the overall yield and profitability of the trial area. There was no evidence that the optimum nitrogen rate varied between the P management strategies, and optimum N rates were near those recommended currently by the U of M. Phosphorus application increased soil P in low testing areas in spite of high soil pH in the short term, but low to no application of phosphorus generally decreased it in Medium and High testing areas. Removal based P rates in the BPM strategy on average resulted in soil test P increases. Net returns to P were the highest when soils tested Low to Medium. The SLAN strategy always resulted in a higher profit potential, but both strategies were profitable in Low and Medium testing soils if P fertilizer price was either \$0.50 or \$1.00 per lb. P_2O_5. Decisions on which strategy to use should be based on grower goals and land-tenure. Grid sampling can be used to vary fertilizer application rates to better utilize inputs in a varying landscape as long as the sampling scheme accurately represents the variability within the field.

Appendix

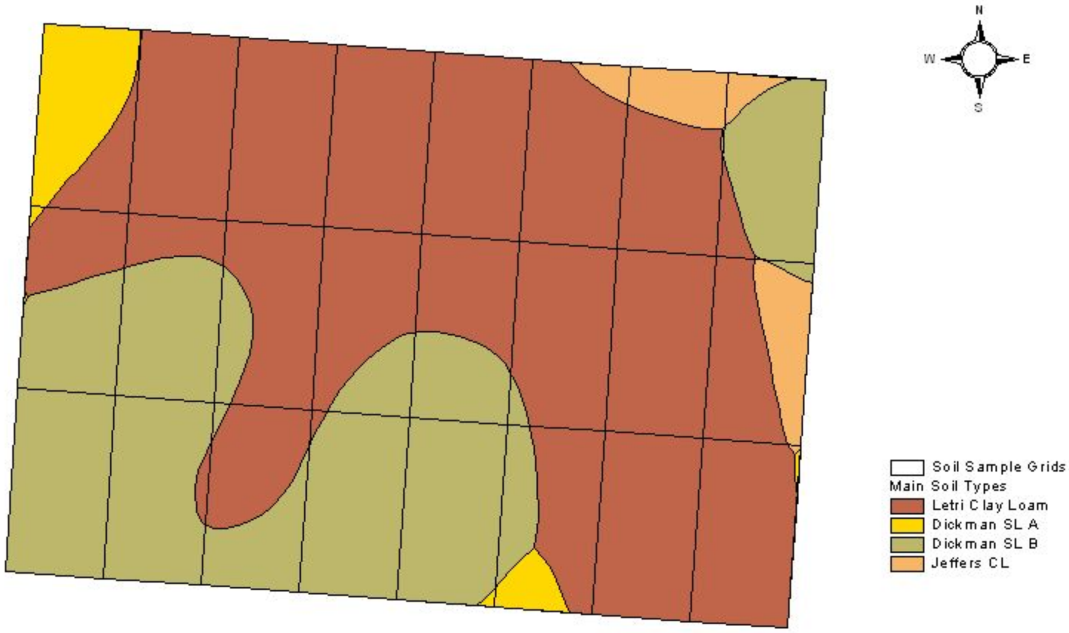

Figure 1. Trial layout and soil classifications

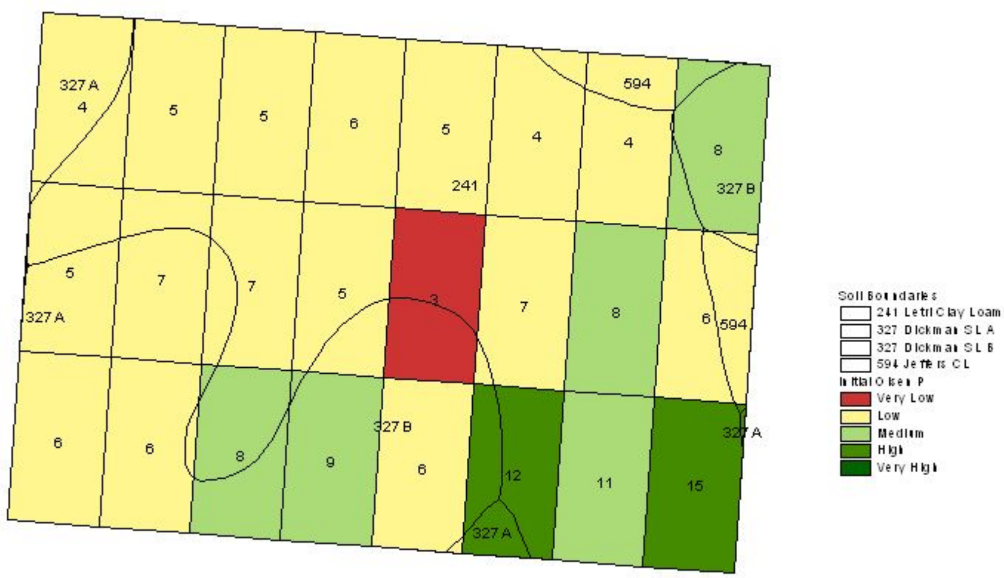

Figure 2. Initial Olsen-P classifcations and soil test values.

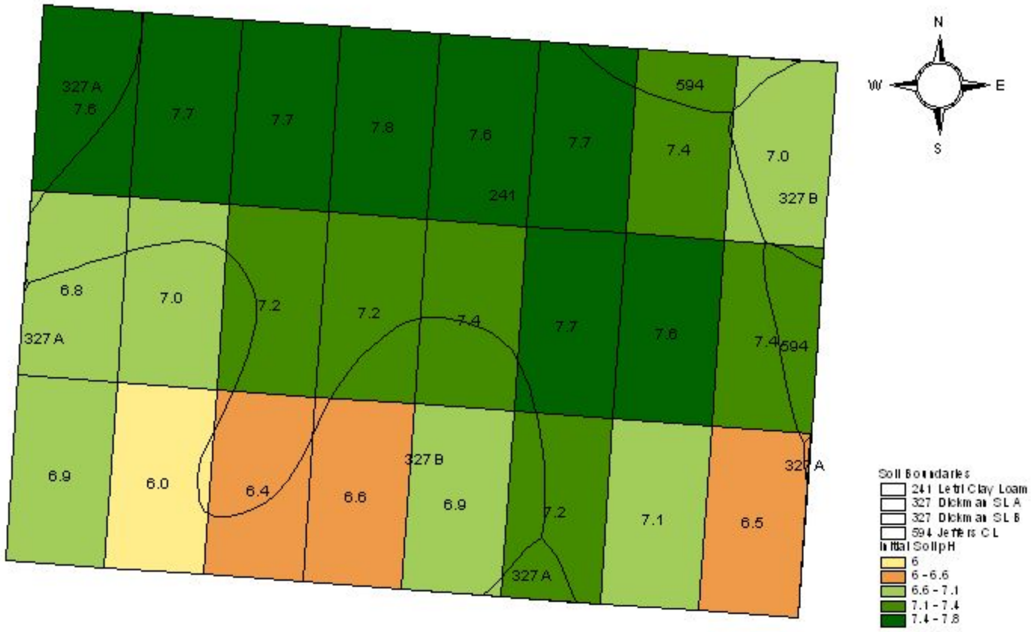

Figure 3. Initial soil pH values for each grid cell.

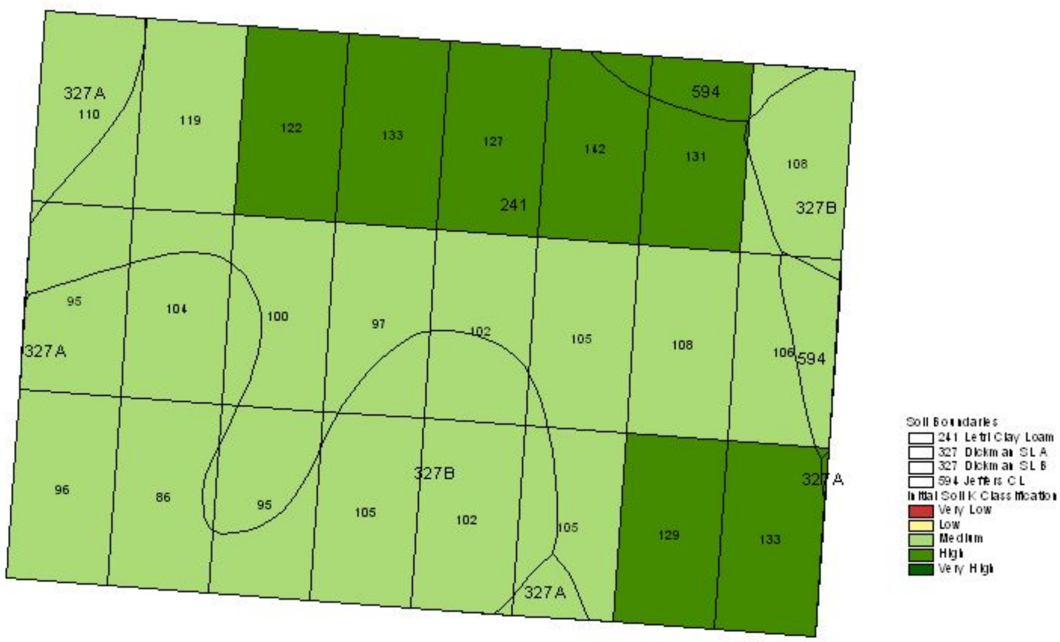

Figure 4. Initial soil potassium values for each grid cell.