Minnesota Long-Term Phosphorus Trial: Phase II, Testing Yield Response and Potential

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Phosphorus management is critical to reduce environmental risk while sustaining field productivity. Phosphorus (P) is an essential nutrient and the second most commonly applied nutrient in Minnesota agriculture. Phosphorus fertilizer management is based on one of two philosophical approaches, Build and Maintain (B&M) and Sufficiency (Olson et al., 1987). The B&M approach recommends P fertilizer quantities needed to build the soil test P (STP) to or near a critical level over a period of years. The critical level is that STP level where there is less than a 5% chance the crop will respond to additional fertilizer. Once the target STP level is reached, annual applications of P fertilizer based on P removal of previous crop are required to maintain that STP. These applications are frequently based on P removal in the previous crop.

The B&M approach uses STP to monitor the perceived soil fertility status of the field. The Sufficiency approach uses STP to determine the likelihood that P fertilizer will increase crop yield and the rate of fertilizer required to optimize that yield. The B&M approach does not directly account for the soils natural ability to supply P, but supplies needed P through off-site sources such as commercial fertilizer or manure. The Sufficiency approach relies on the soils natural P supplying capability and supplements that capability with off-site P sources. The objective of both approaches is to maximize net returns to the growers. Under ideal conditions, the Sufficiency approach presumes to maximize economic return for each dollar of P fertilizer applied. The B&M approach presumes to prevent any chance of P deficiency and maximize overall yield potential.

Minnesota research has shown different soils to require differing amounts of P fertilizer to raise and maintain STP. Discussions, debates, and arguments supporting one approach verses the other are good academic exercises engaged in by academicians and practitioners.

They are also the basis of current P fertilizer recommendations and objectives from the University of Minnesota, fertilizer dealers, and growers. Current P recommendations for corn and soybean in Minnesota are determined based on expected crop yield and soil test P levels (Kaiser et al., 2011; Kaiser and Lamb, 2012; Kaiser et al., 2016).

Research in the 1970s and 1980s found similar grain yied between both approaches, with greater profitability with the Sufficiency approach which applied less P fertilizer. In recent years, it is argued that greater fertilizer applications associated with the B&M approach are necessary to obtain and maintain greater production levels in today's agricultural systems. There is concern if the Sufficiency approach will maximize yield potential.

The primary goal of this project is to establish long-term field trials at several locations across Minnesota to test P management strategies. These trials will be developed in phases each with its own set of objectives.

Phase I was the establishment of the long-term trials starting in the fall of 2010 and terminating in the fall of 2014. In Phase 1, we reached the objective of established experiments with STP interpretation classes ranging from Low, Medium, High, and Very High developed (built) over a period of four growing seasons (2011-2014).

Phase II started in 2015 and finished in 2017. The specific objective of Phase II was to determine if corn or soybean maximum yield potential differs in soil systems managed with B&M or Sufficiency strategies. The main objectives of Phase II are:

Objective 1- Initiation of Phase II: Evaluate corn yield and P uptake response to P fertilizer within each STP category developed during Phase I.

Objective 2- Determine if the maximum yield achieved within each STP treatment developed during Phase I differs regardless of the actual response to P fertilizer applied in Phase II.

Objective 3- Fractionation of soil phosphorus (P): Determine the effects of previous P management, development of various STP categories in Phase I, on soil P fractions or pools.

Materials and Methods:

Six experimental sites were located at various locations across Minnesota representing the major production agricultural regions of the state. All sites were located on University of Minnesota Research and Outreach Centers (ROC) except for one near Rochester, which has been managed by the Southern ROC for a couple of decades. Experimental sites were located near Becker (Sand Plain Experimental Research Farm), Crookston (Northwest ROC), Lamberton (Southwest ROC), Morris (West Central ROC), Waseca (Southern ROC), and Rochester (managed by Southern ROC). Soil characteristics of each experimental site are presented in Table 1.

At each site, a split-plot randomized complete block experimental design was used with four blocks or replications. The whole plot treatment is the targeted or established STP Interpretation Class. Minnesota soil test P ranges for each targeted soil interpretation class were 0-5 (BrayP) or 0-3 ppm (OlsenP) for Very Low, 6-10 (BrayP) or 4-7 ppm (OlsenP) for the Low, 11-15 (BrayP) or 8-11 (OlsenP) for the Medium, 16-20 (BrayP) or 12-15 (OlsenP) for the High, and 21+ (BrayP) or 16+ (OlsenP) for the Very High soil interpretation classes (Kaiser et al., 2016).

Phase II of this project marks the first time treatments were applied on the split-plot basis. During Fall 2014 after harvest, four split-plots were delineated within each whole plot. Two split-plots within each whole plot were used during 2015 corn growing season, and the remaining 2 split-plots were used during 2016 corn growing season. For the 2017 soybean, the control plots were utilized in each main plot which had been maintained following similar practices used to build soil test values.

For the split plots, one did not received P fertilizer and the following crop will rely on the soil residual P that has been built up, or drawn down, during Phase I. The second split-plot received a broadcast application of P fertilizer at the rate of 150, 90, 30 and 30 lbs. P_2O_5 ac^{-1} for the Low, Medium, High and Very High (VHigh) STP category treatments developed during Phase I. The rates selected for use for the applied treatment constituted the suggested rate for the soil test and yield level plus 50%. Triple superphosphate (0-46-0) was the only P fertilizer source used at all locations. Phosporus fertilizer was broadcasted and incorporated.

Crop rotation was corn (2011)-corn (2012)-corn (2013)-soybean (2014)-corn (2015)-corn (2016)-soybean (2017) for all locations except Crookston which the rotation was corn (2011)-soybean (2012)-wheat (2013)-soybean (2014)-corn (2015)-corn (2016)-soybean (2017). The actual tillage and overall crop rotation varies among the six sites because of specific geographic regions in which they are located.

Soil samples were taken from each split-plot to a depth of 6 inches (9 cores that were composited to one sample) from mid-summer to late fall or early spring, depending on the site during the 2015 corn growing season. Soil samples were dried, ground, and shipped to Agvise Laboratories. Soil test P was determined using three conventional methods: Olsen P, Bray P1, and Mehlich III (Frank et al., 1998).

Grain yield (adjusted to 15.5% and 13% moisture for corn and soybean, respectively), grain P concentration (measured by ICP following wet digestion (Gavlak et al., 2005), and P removal by grain were measured each year at all experimental sites. Soybean grain protein and oil content were assessed by NIR and reported at 13% moisture content.

Statistical data analysis was performed using PROC GLIMMIX (SAS, Institute 2012) assuming fixed effects Site, Soil P category, and P fertilizer application and random blocking effects.

In 2014, prior to any P fertilizer being applied as treatments in preparation for Phase II of this experiment, soil samples were collected and sent the analytical laboratory at NWROC for soil P fractionation procedures. Three soil cores, ¾ inch in diameter were collected from each split-plot within a whole plot to a depth of 12 inches. Cores were divided into depths of 0-3 inches, 3-6 inches, and 6-12 inches. From the four split-plots within a whole plot a total of 12 cores were collected and composited by depth. The soil samples were air dried and ground in preparation for lab analysis.

The soil P fractionation procedure is a detailed sequential process whereby a 1 gm sample of soil is sequentially exposed to a variety of P extracting solutions, each more harsh than the previous. The first extraction is with an anion exchange resin that will bind soil P from the soil solution and that P readily exchanged between the solid phase and the soil solution. The second extraction is with sodium bicarbonate that measures exchangeable P and also has an organic P component. Both the resin extracted and sodium bicarbonate extracted

P are considered readily available sources of soil P for the growing crop. The next two sequential fractions are with sodium hydroxide, the second with with sonication. Both of these fractions have an inorganic and organic P component and are considered moderately available sources of P for the growing crop. Moderately available means that the P can migrate into the available P pools with time. However, the rate this P moves to the available pool may not be sufficient to meet crop P demands. The final two extractions are Hydrochloric Acid and a digestion of all that is left. The Hydrochloric Acid extraction is inorganic P that is considered slowly available or highly unavailable P. That is, its migration to the available soil P pool is so slow it will not meet crop P demands. And finally the residual P is all the P left after all the previous extractions. It is a combination of both inorganic and organic P that is considered very highly unavailable.

For purposes of this report, we are reporting the fractionation data as Available, Moderately Available, Unavailable, and Organic P. We have combined the various extractions into these primary categories. In addition, we have combined the fractions from the 0-3 and 3-6 inch soil depths for purposes of this report.

Summary Results

At the end of Phase I (2014), all sites had reached significantly differences among the four established interpretation classes: Very High > High > Medium > Low classes (Fig. 1). All the target Interpretation Classes have been reached within the range established for Minnesota, with some cases exceeding by some small margin. Soil test P for each interpretation class was determined using Olsen procedure for Crookston and Morris because both are calcareous soils with higher pH, and Bray-P procedure was reported for all the other sites (Becker, Lamberton, Waseca, Rochester). Fertilizer P applications have been continuously modified to fit the immediate need to achieve the objectives of this Phase I.

Objective 1:

The results presented in this report correspond to the three years of Phase II. Trials entered Phase II in the fall of 2014. Grain yield and grain P removal response to the added P fertilizer were determined and compared across STP Interpretation classes. Corn was grown at all sites in 2015 and 2016, and results are presented as an average of both growing seasons. Soybean was grown during the 2017 growing season.

At **Becker**, corn grain yield and grain P removal were significantly higher in the applied-P (+P) than in the noP-applied (-P) treatments at the Low and Medium STP class (Fig. 2 and 3, Table 2 and 3). Grain yield increased 64 and 34 bu ac^{-1} with P application in the Low and Medium STP classes. Similar corn grain yields and grain P removal were observed whether fertilizer P was applied or not in the High and Very High STP classes (Fig. 2 and 3, Table 2 and 3). Soybean yields were similar across treatments in 2017, but soybean P removal was significanlty greater in the applied-P (+P) than in the noP-applied (-P) treatments only at the Low STP class (Fig. 4 and 5, Table 4 and 5). The lack of differences and suppresed yield among treatments in 2017 could be attributed to the incidence of white mold on the field. Soybean protein content in the High (36.4%) STP class was similar than Low (36.2%) but higher than Medium (35.7%) and Very High (35.9%) STP class (Table 6). Oil content was similar between Very High (16.8%) and Medium (16.9%) STP class but significantly higher than High (16.6%) STP class (Table 7).

Corn grain yield and grain P removal were not significant different between the noP-applied (-P) and the applied-P (+P) treatment at any of the STP classes at **Lamberton** (Fig. 2 and 3; Table 2 ad 3). In 2017, soybean yield and soybean P removal were significantly higher in the applied-P (+P) than in the noP-applied (-P) treatments at the Low and Medium STP class (Fig. 4 and 5, Table 4 and 5). Soybean protein and oil content were similar across treatments (Table 6 and 7).

At **Waseca**, corn grain yield and grain P removal were significantly higher in the applied-P (+P) than in the noP-applied (-P) treatments at the Low and Medium STP class (Fig. 2 and 3, Table 2 and 3). Corn grain yield increased 26 and 11 bu ac^{-1} with P application in the Low and Medium STP classes. In the High and Very High STP classes, similar grain yield and grain P removal were observed between noP- and applied-P treatments (Fig. 2 and 3, Table 2 and 3). In 2017, soybean yields were significantly higher in the applied-P (+P) than in the noP-applied (-P) treatments at the Low, Medium and High STP class (Fig. 4, Table 4).

Soybean P removal was significantly higher in the applied-P (+P) than in the noP-applied (-P) treatments at the Low and Medium, with no differences in the High and Very High STP class (Fig. 5, Table 5). Soybean protein content was similar across treatments (Table 6). Oil content was significantly higher in the the noP-applied (-P) than applied-P (+P) treatments at the Low STP class (Table 7).

At **Rochester**, corn grain and soybean yields had no significant response to applied-P (+P) for any of the STP classes (Fig. 2 and 4, Table 2 and 4). However, corn grain and soybean P removal was significantly higher in the applied-P than in the noP-applied treatments at the Low and Medium STP classes (Fig. 3 and 5, Table 3 and 5). Soybean protein content was significantly greater in the noP-applied (-P) (34.9%) treatments than the applied-P (+P) (34.7%) treatment (Table 6). Soybean oil content was similar across treatments (Table 7).

At **Morris**, corn grain and soybean yields were similar among treatments (Fig. 2 and 4, Table 2 and 4). Corn grain P removal had not significant response to applied-P (+P) in any of STP class (Fig. 3, Table 3), however in 2017, soybean P removal was significantly higher in the applied-P than in the noP-applied treatments at the Low STP classes (Fig. 5, Table 5). Soybean protein content was significantly higher in the applied-P (+P) than noP-applied (-P) treatments at the High STP class (Table 6). Similar oil content was observed among treatments (Table 7).

Grain yield was significantly greater in the applied-P treatments in the Low STP class at **Crookston** (Fig. 2, Table 2). Grain yield increased 41 bu ac^{-1} in the Low STP class. Grain P removal was significantly greater in the applied-P (+P) than noP-applied (-P) treatments in the Low and Medium STP classes (Fig. 3, Table 3). In 2017, soybean yields and soybean P removal were similar across treatments (Fig. 4 and 5, Table 4 and 5). Soybean protein content was significantly higher in the applied-P (+P) than noP-applied (-P) treatments only at the Low STP class (Table 6). Oil content was significantly lower in the applied-P (+P) than noP-applied (-P) treatments only at the Low STP class (Table 7).

Overall, 2 of the 6 sites (Becker, Crookston), 3 of the 6 sites (Becker, Crookston,Waseca) and 2 of the 6 sites (Lamberton, Waseca) during 2015, 2016 and 2017 growing seasons, respectively, showed significant response to applied-P (+P) on grain yield in the Low and/or Medium STP classes. Grain P removal was more responsive at all growing seasons, and 4/5 of the 6 sites showed greater P removal with applied-P especially in the Low and Medium STP classes.

Objective 2:

The greatest response to fertilizer P was in the Low and Medium STP classes as expected. There was little to no response to applied P in the High or Very High STP classes (Fig. 6).

At all 3 yrs of Phase II there was no evidence at any of the sites that building and maintaining a high soil test level had a greater grain yield potential than applying P fertilizer annually based on soil test level regardless what that level was. That is, the Sufficiency Approach was just as productive with P fertilizer applied to Low or Medium soil testing P soils as higher testing P soils with or withour P fertilizer applied.

Therefore, a build and maintain fertilizer approach would only result in greater input (fertilizer) costs and would not result in greater corn yields. A build and maintain approach can provide some flexibility when fertilizer P prices increase unexpectedly.

Objective 3:

Objective 3 indicates we wanted to fractionate the soil P in its various pools representing various levels of availability to the crop. In reality, this objective was designed to provide the data necessary to go a step further. These fractionations were completed on soils collected at the end of Phase I before any treatments were applied for Phase II. The same fractionation procedure was conducted on soils collected at the initiation of the trial before any treatments were applied for Phase I. Comparing fractionations from initiation and the final year of Phase I will show changes that have occurred in the various soil P pools over this four year period of time.

The relationship bewteen changes in Bray-P or Olsen-P from initial soil test P and the net amount of P applied is shown in Figure 7. After 6 years, when net P addition was 0 (P removed=P applied) a positive net change of 1.5 ppm Bray-P1 P yr^{-1} and 0.2 ppm Olsen P yr^{-1} was observed for acidic and calcareous soils, respectively.

Table 8 shows the total amount of P that was applied as fertilizer to each treatment at each site throughout the four year Phase I period (2011-2014). The table also shows the total amount of P removed in the harvested grain from each treatment at each site. The difference is a deficit or excess of P applied verses removed. A word of caution when looking at these numbers is warranted. Fertilizer P content is provided as a percentage of diphosphate pentoxide (P_2O_5). When we talk about the amount of P fertilizer to applied it is in the same terms. However, only 44% of this number is actually P. What you see in the table is the total amount of P ac^{-1} applied and not P_2O_5 ac^{-1} applied.

Though each site varied somewhat, overall as the amount of P applied increased the amount of P removed in the grain might also have increased, but not to the same extent. Therefore, as P applied increased there was an increase in excess P supplied relative to the need. In the Low treatment where no P fertilizer was applied, there was a deficit at all sites. In the Medium treatment, there was a mix of deficit and excess among the sites. In the High and V. High treatments, there was always excess P. The exception was Rochester in the High treatment. There was also considerably variability among the sites as to the level of deficit and excess P. This was caused by variation in P fertilizer applied among the sites as attempts were made to develop the targeted STP Interpretation Classes during this Phase I period as well as the crop and level of yield variation among the sites.

This table raises the questions we asked that warranted the fractionation process. If there is a deficit in P applied relative to P removed, from what soil P pool was the P supplied to the crop? And second, if there is excess P applied relative to P removed, to what soil P pool did the excess P go?

There is a tremendous amount of data in this fractionation component and the analyses is still on-going. However, we can show a glimps of what what we are seeing to this point.

Figure 8 illustrates the change in Readilty Available P (RAP) during Phase I at the six sites and each whole plot treatment. For the most part, there were only small variations in RAP among whole plots the initiation of the trial. Morris had the most variability at the start. At the end of four years there was a consistencly among all the sites. As the STP

Interpretation Class went from Low to Medium to High (labelled as SHigh in the figures) to V. High there was a stair step increase in RAP. At almost all sites there was a decrease in RAP in the Low treatment with little change or perhaps a slight increase in RAP in the Medium treatment. There was a substantial increase in RAP in the High and Very High treatments. There were a couple of exceptions in this summary. First, there was little change in RAP in the Low treatment at Lamberton. This corresponded with the least deficit P of the six sites (Table 8). Second, there was an increase in RAP in the Medium treatment at Crookston, Lamberton and, to a less extent, at Waseca. These three sites had excess P in the Medium treatment or the lowest deficit as at Waseca (Table 8).

Moderately Available P (MAP) also increased as the target STP Interpretation Class went from Low to Medium to High (SHigh in the figure) to V. High (Figure 9). However the changes from the initiation of the trial to the conclusion of Phase I was not as dramatic as that of RAP. In the Low treatment, there was a decrease in MAP at Crookston, Morris, Rochester, and Waseca over this period. There was no change during this period at Becker and Lamberton. In the Medium treatment, Lamberton and Becker indicated an increase in MAP during this period with little to no change in the other sites. Moderately Available P increased at all sites in the High and Very High treatments. Interestingly the increase at Rochester and Crookston were only slight compared to the other sites.

The Slowly Available P represented the highest proportion of soil P at all sites, but there was a substantial variation in the quantity of this soil P among the sites (Figure 10). During the four years of Phase I there was little to no change in the Slowly Available P at all the sites for all the treatments.

Figure 11 illustrates the changes in Organic P that occurred during Phase I. All the sites and all treatments suggest a slight increase in Organic P during this period. The analysis necessary to divide the Organic P into the Readily Available and Moderately Available P has yet to be done. What is obvious from Figure 10 is the variability in Organic P among the sites. What is apparent in this data is that deficit P was supplied primarily from the Readilty Available P and to a less extent from the Moderately Available P pools. Excess P contributed to the Readily Available P as well as the Moderately Availability P. The extraction process used to determine these various pools is a sequential extraction process with the designation of Readily and Moderately etc Availability a box that includes certain fractions. In reality, the movement of P through these various cateogories of availability is more a continuum and not a movement from one box to another. What cannot be discerned from this data is whether P that migrated to the Moderately Available P pools will readily move back into the Readily Available P pools. That is, how readily the Moderately Available P will supply a crop with needed P would require additional years of experiments.

Because the Slowly Available P pool is already relatively large at all the sites, detection of additional P into or substraction of P from this pool requires the movement of relativley large amounts of P. Therefore the role of this pool to the crop in a P deficit or a P excess sitaution cannot be determined in this trial or at least in the current life span of the trial. Obviously, we would expect a decrease in the Slowly Available P pool in the Low treatment, but it would not be sufficient to meet crop needs as indicated by the response to applied P fertilizer in this treatment in Phase II of this trial. On the other hand, a building of the Slowly Available P pool might be expected in the V. High and possibly the High treatments, but it may take several years before it is detected. Analysis of this data will continue in an attempt to understand the differences in soil characteristics among the sites and relate those differences to potential differences in crop response to building STP levels and to applied fertilizer P.

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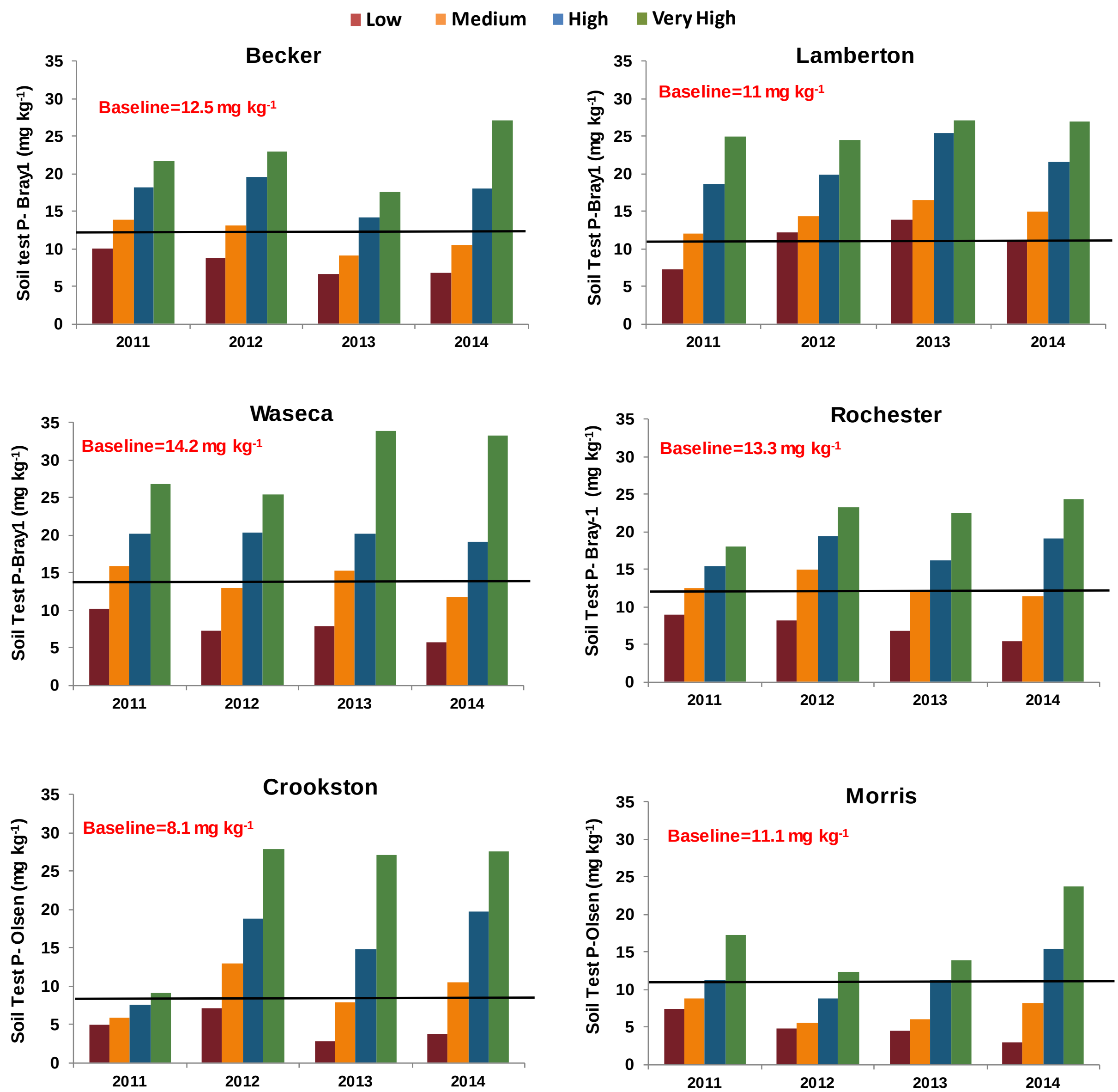


Figure 1. Extractable soil P (mg kg^{-1}) measured as Bray-1 for Becker, Lamberton, Waseca, and Rochester, and as Olsen-P for Morris and Crookston for the four growing seasons (2011-2014)-Phase I at the Low, Medium, High and Very High soil test P interpretation classes.

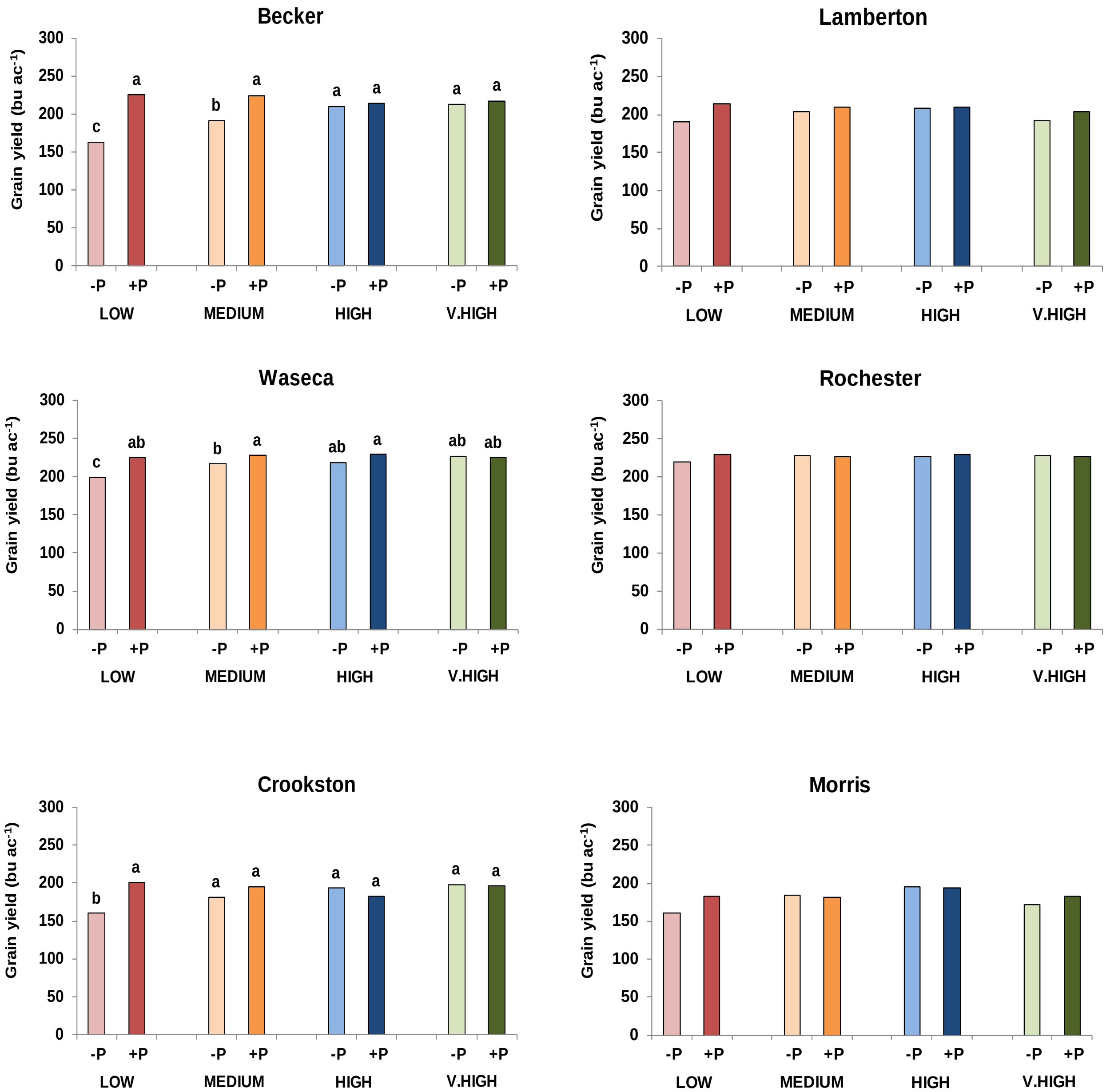


Figure 2. Corn grain yield (bu ac^{-1}) response to applied-P (+P) and noP-applied (-P) treatments at the Low, Medium, High and Very High soil test P interpretation classes for all experimental sites. Average of 2015 and 2016 corn growing season.
Different letters indicate significant differences at $P < 0.05$.

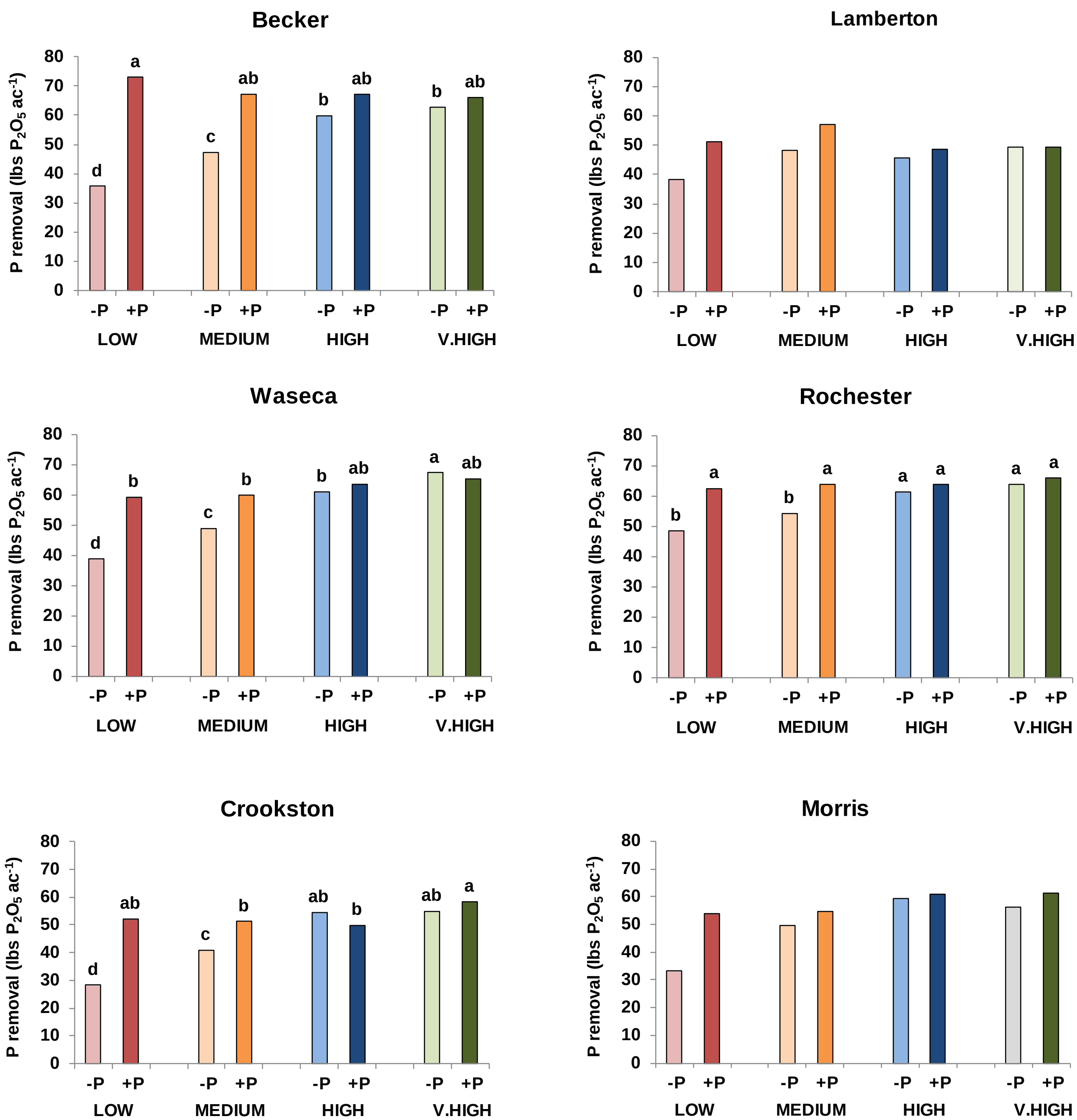


Figure 3. Grain P removal (lbs P_2O_5 ac^{-1}) response to applied-P (+P) and noP-applied (-P) treatments at the Low, Medium, High and Very High soil test P interpretation classes for all experimental sites. Average of 2015 and 2016 corn growing season.
Different letters indicate significant differences at $P < 0.05$.

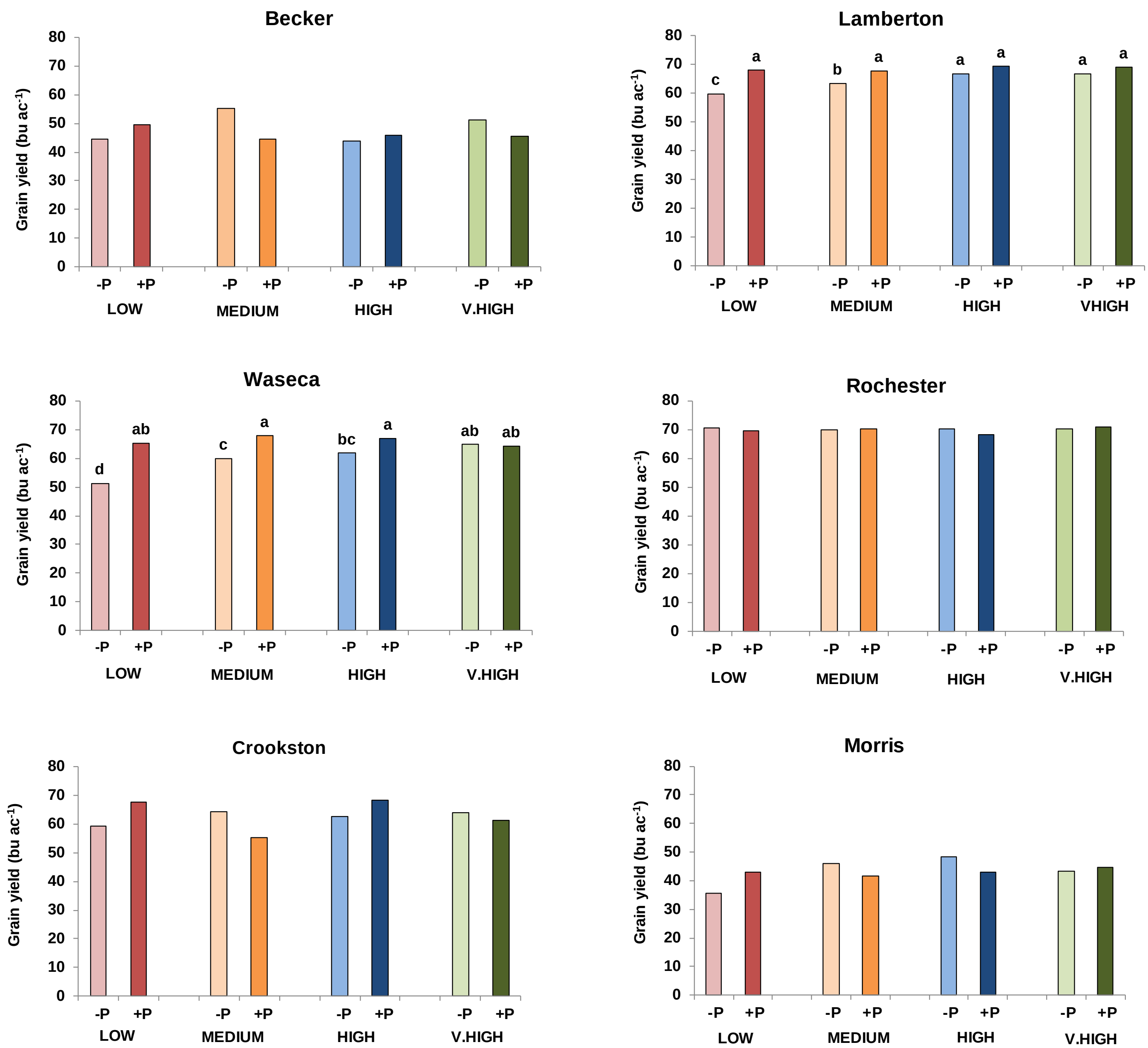


Figure 4. Soybean yield (bu ac^{-1}) response to applied-P (+P) and noP-applied (-P) treatments at the Low, Medium, High and Very High soil test P interpretation classes for all experimental sites. 2017 soybean growing season.
Different letters indicate significant differences at $P < 0.05$.

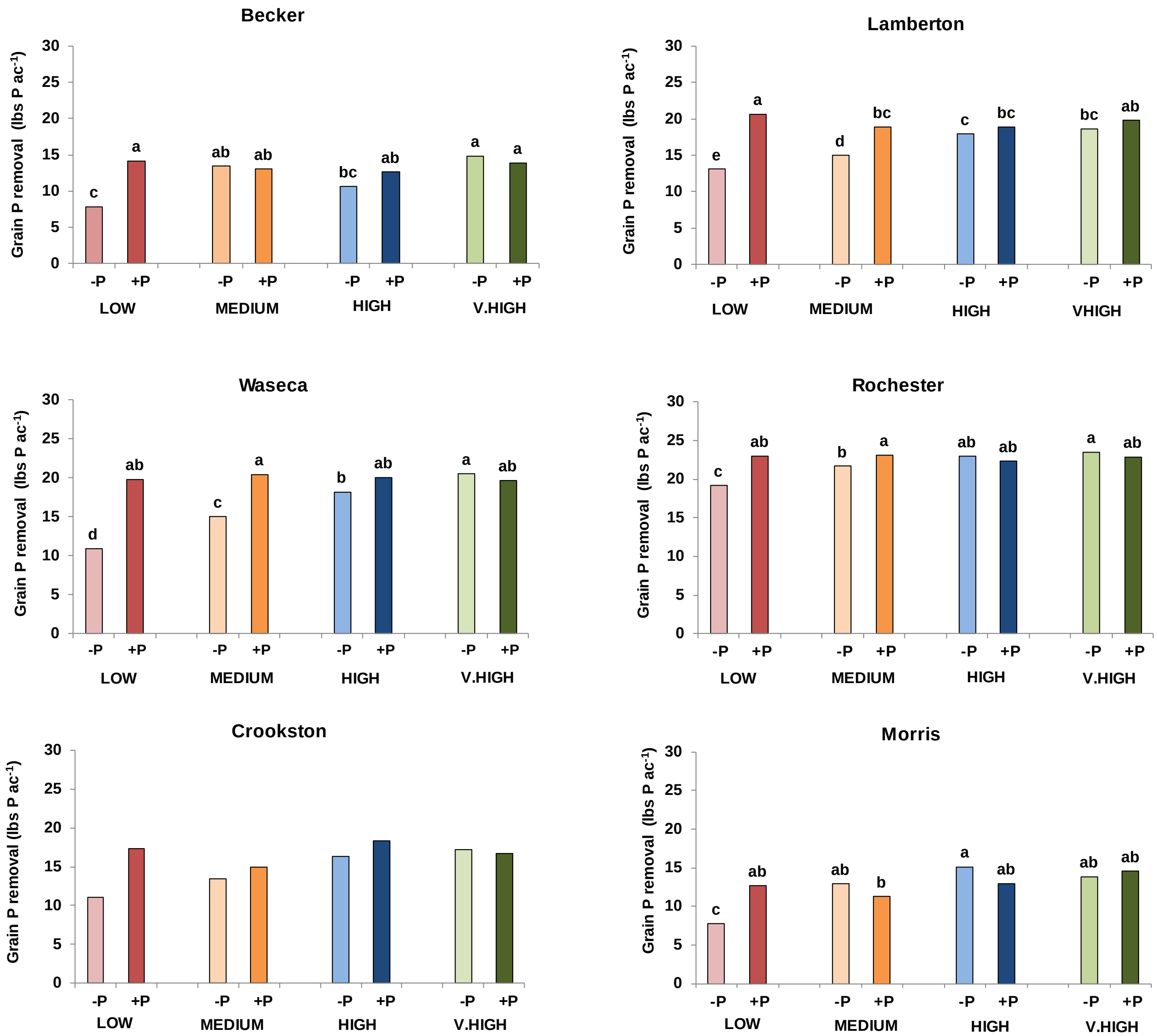
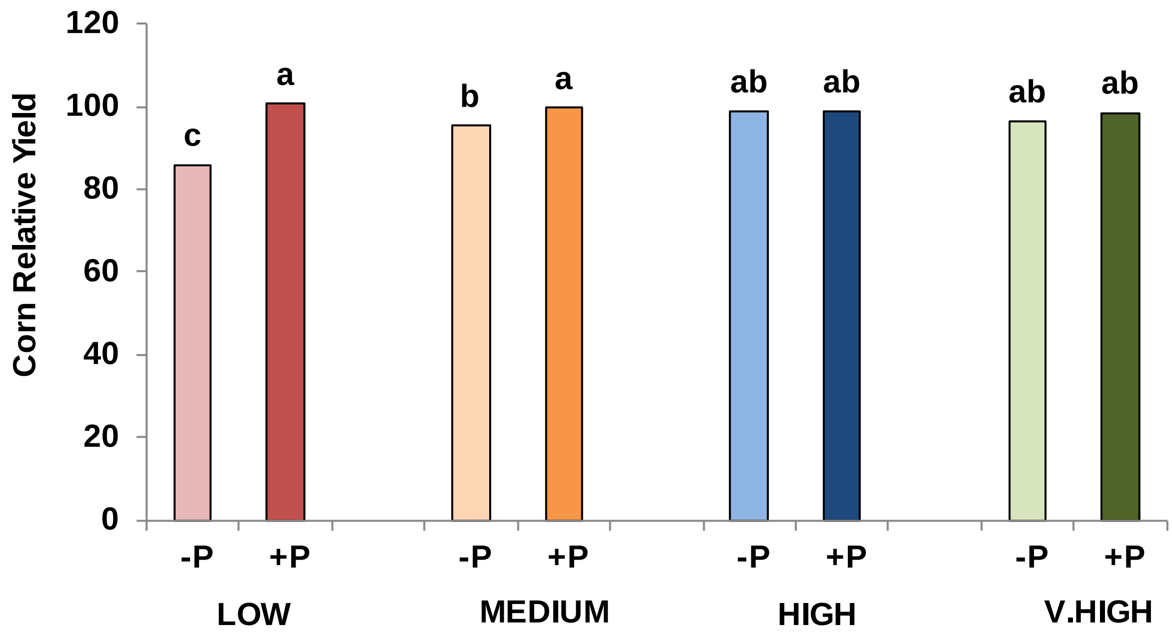


Figure 5. Soybean P removal (lbs P_2O_5 ac^{-1}) response to applied-P (+P) and noP-applied (-P) treatments at the Low, Medium, High and Very High soil test P interpretation classes for all experimental sites. 2017 soybean growing season.
Different letters indicate significant differences at $P < 0.05$.


120
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40
20
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Corn Relative Yield
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b
a
ab
ab
ab
ab
-P
+P
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+P
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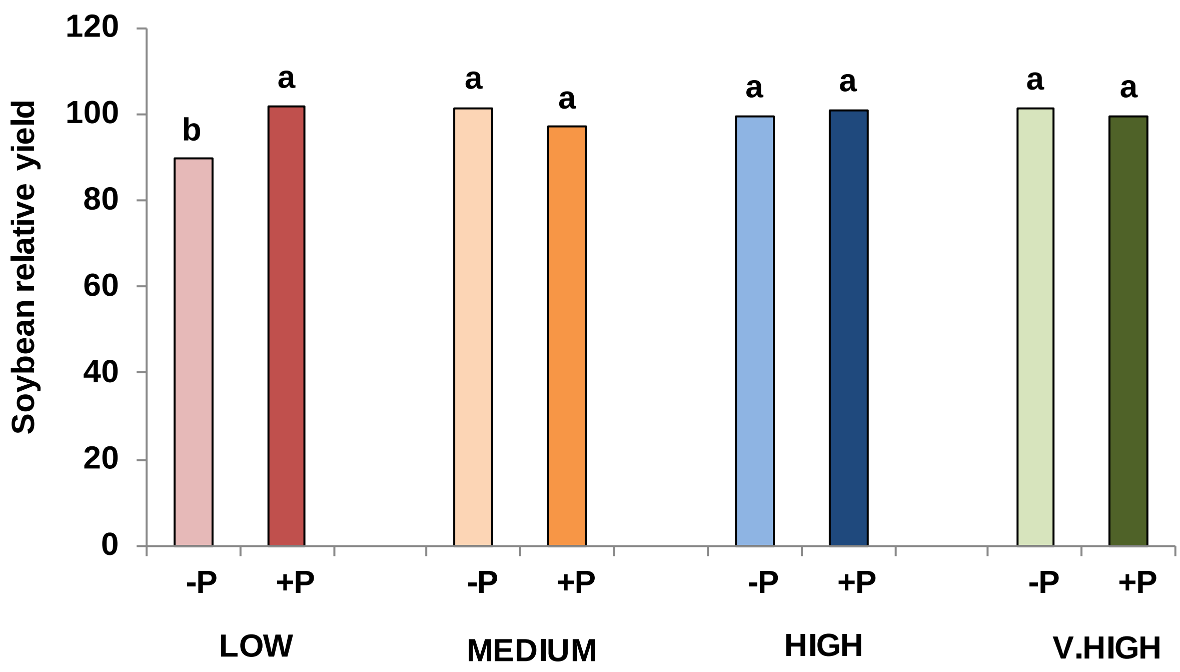
+P
-P
+P
LOW
MEDIUM
HIGH
V.HIGH


120
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40
20
0
Soybean relative yield
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a
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a
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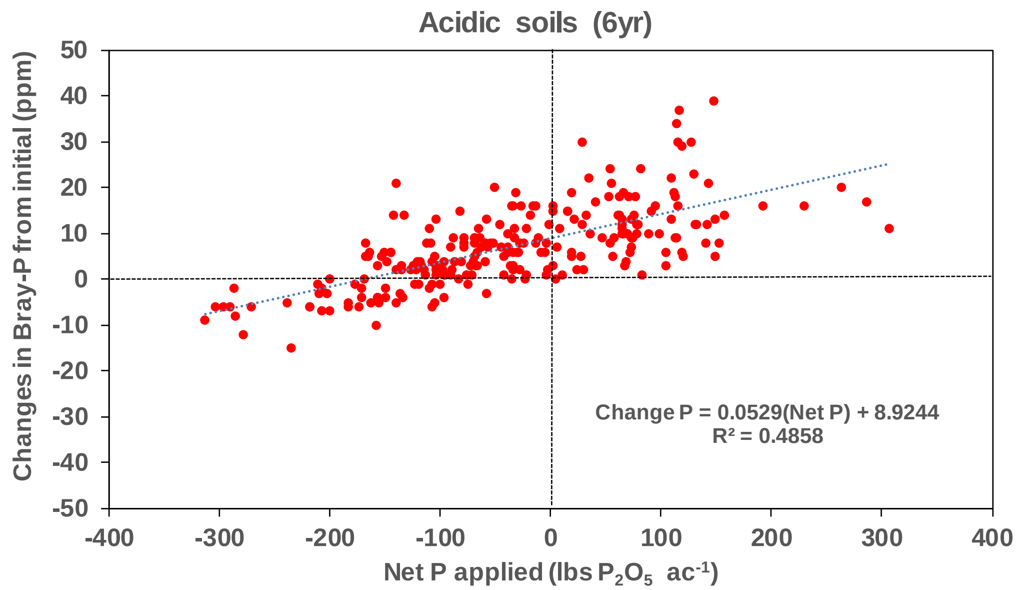
a
a
-P
+P
-P
+P
-P
+P
-P
+P
LOW
MEDIUM
HIGH
V.HIGH

Figure 6. Corn (2015, 2016) and soybean (2017) relative yield average across experimental sites during Phase II. Means with different letter indicates significant differences (Interaction Class x Prate, P<0.05).



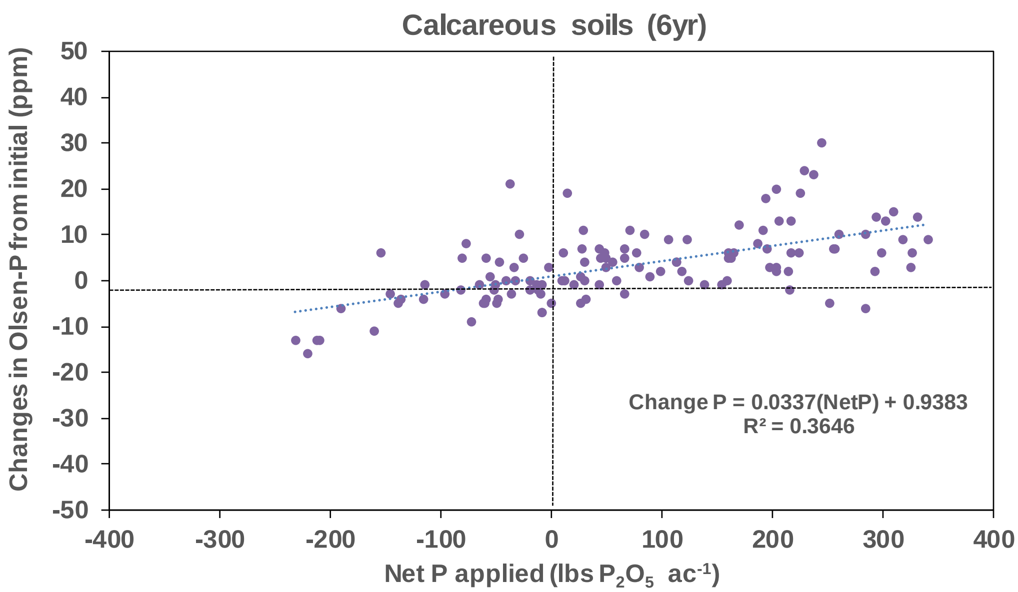


Figure 7. Changes in soil test P (STP) and net P_2O_5 applied average across experimental site for acidic and calcareous soils.

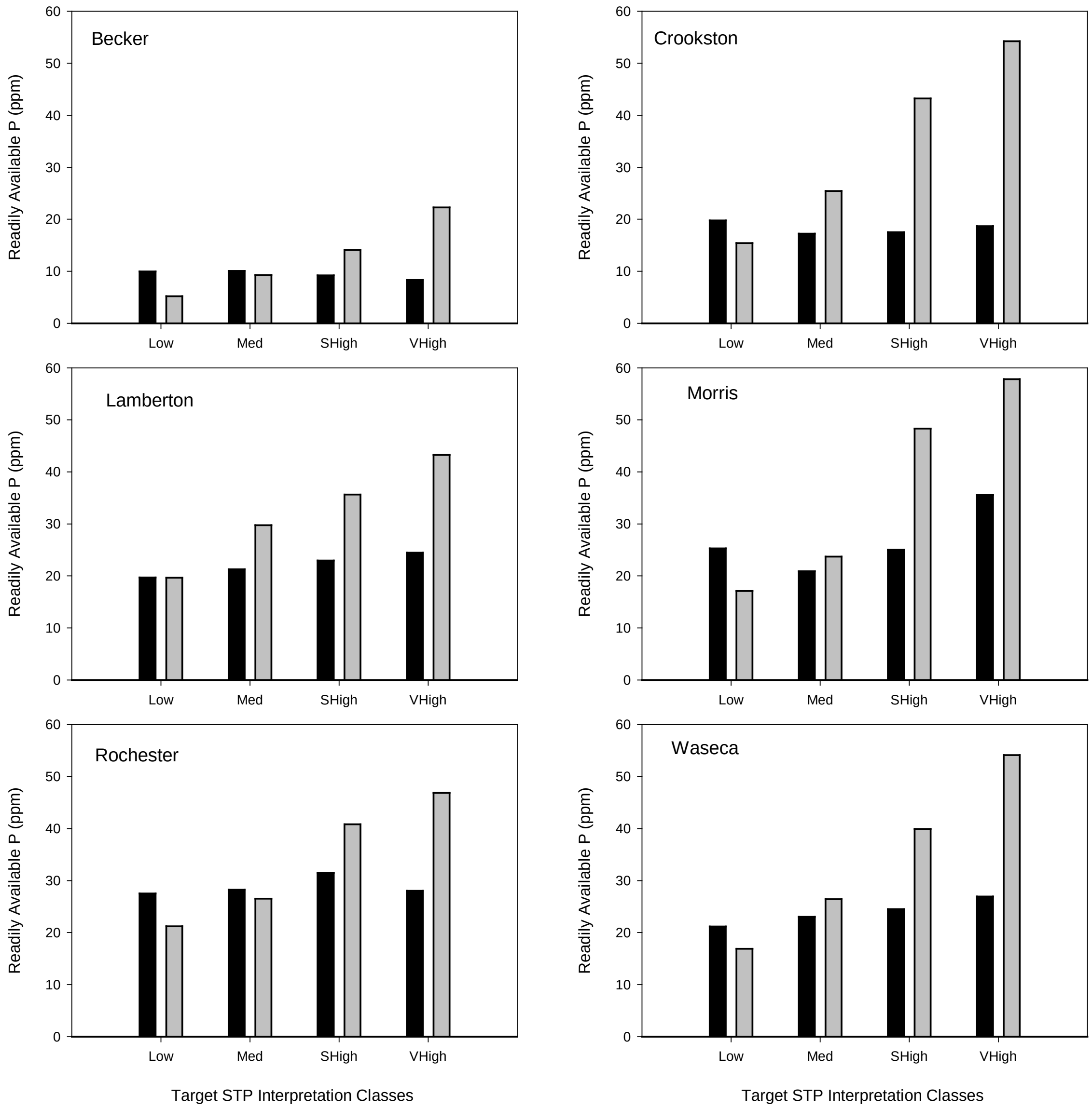


Figure 8. Readily available phosphorus (P) changes in the 0-6-inch soil depth from the initiation of phase I (Fall 2010: black bars) to the completion of phase I (Fall 2014: gray bars) as affected by the target STP Interpretation Class.

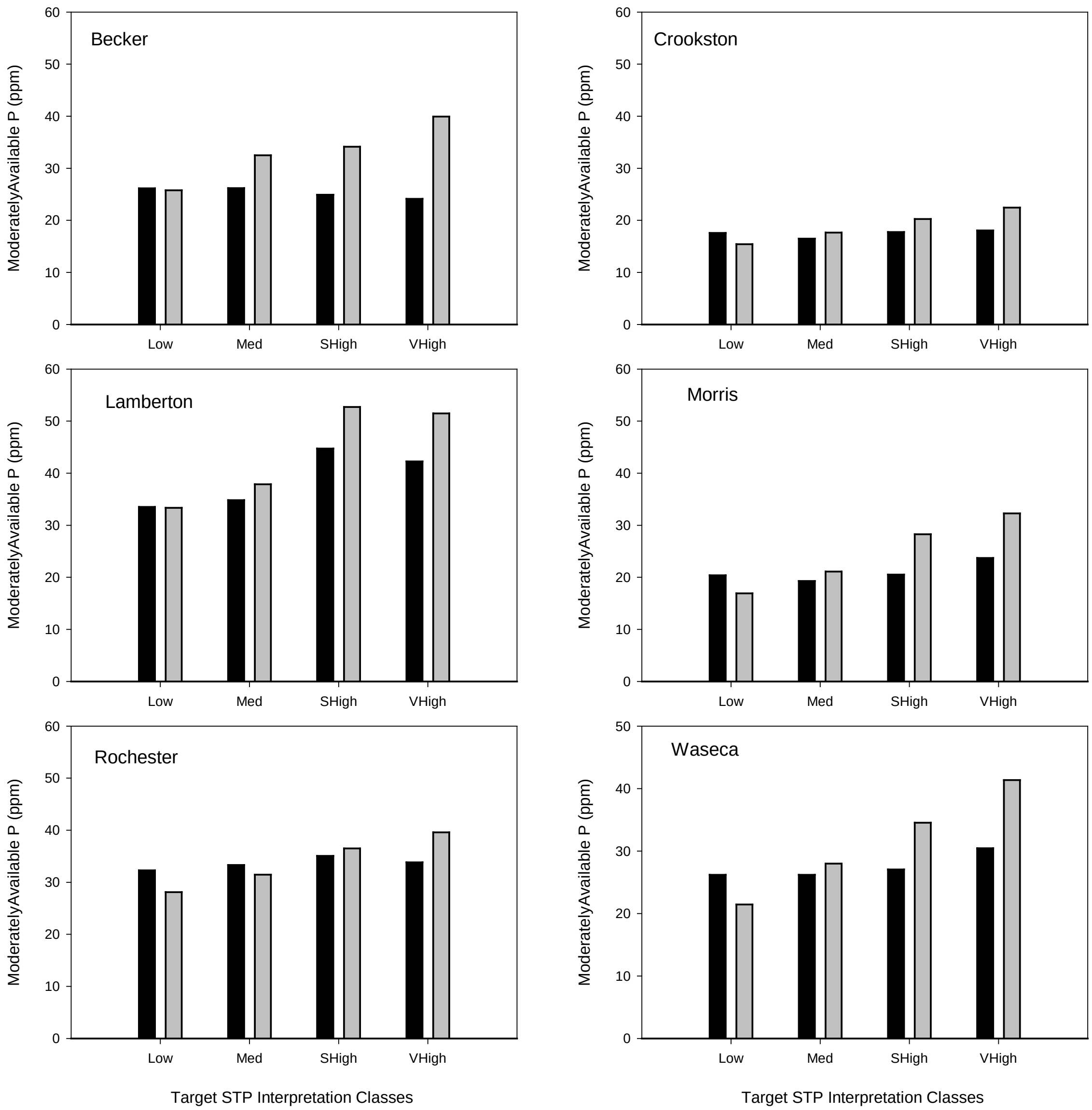


Figure 9. Moderately available phosphorus (P) changes in the 0-6 inch soil depth from the initiation of phase I (Fall 2010: black bars) to the completion of phase I (Fall 2014: gray bars) as affected by the target STP Interpretation Class.

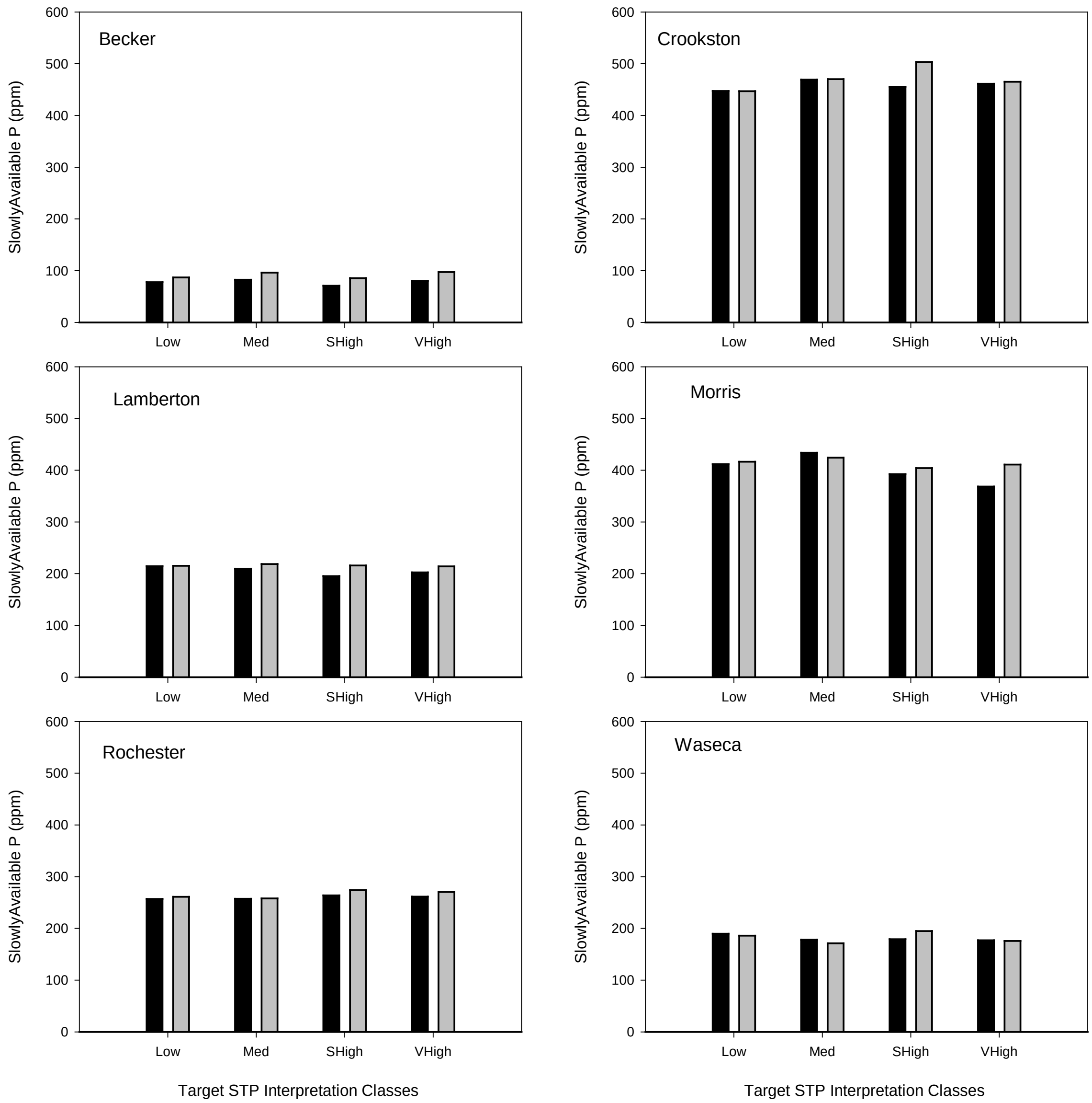


Figure 10. Slowly available phosphorus (P) changes in the 0-6 inch soil depth from the initiation of phase I (Fall 2010: black bars) to the completion of phase I (Fall 2014: gray bars) as affected by the target STP Interpretation Class.

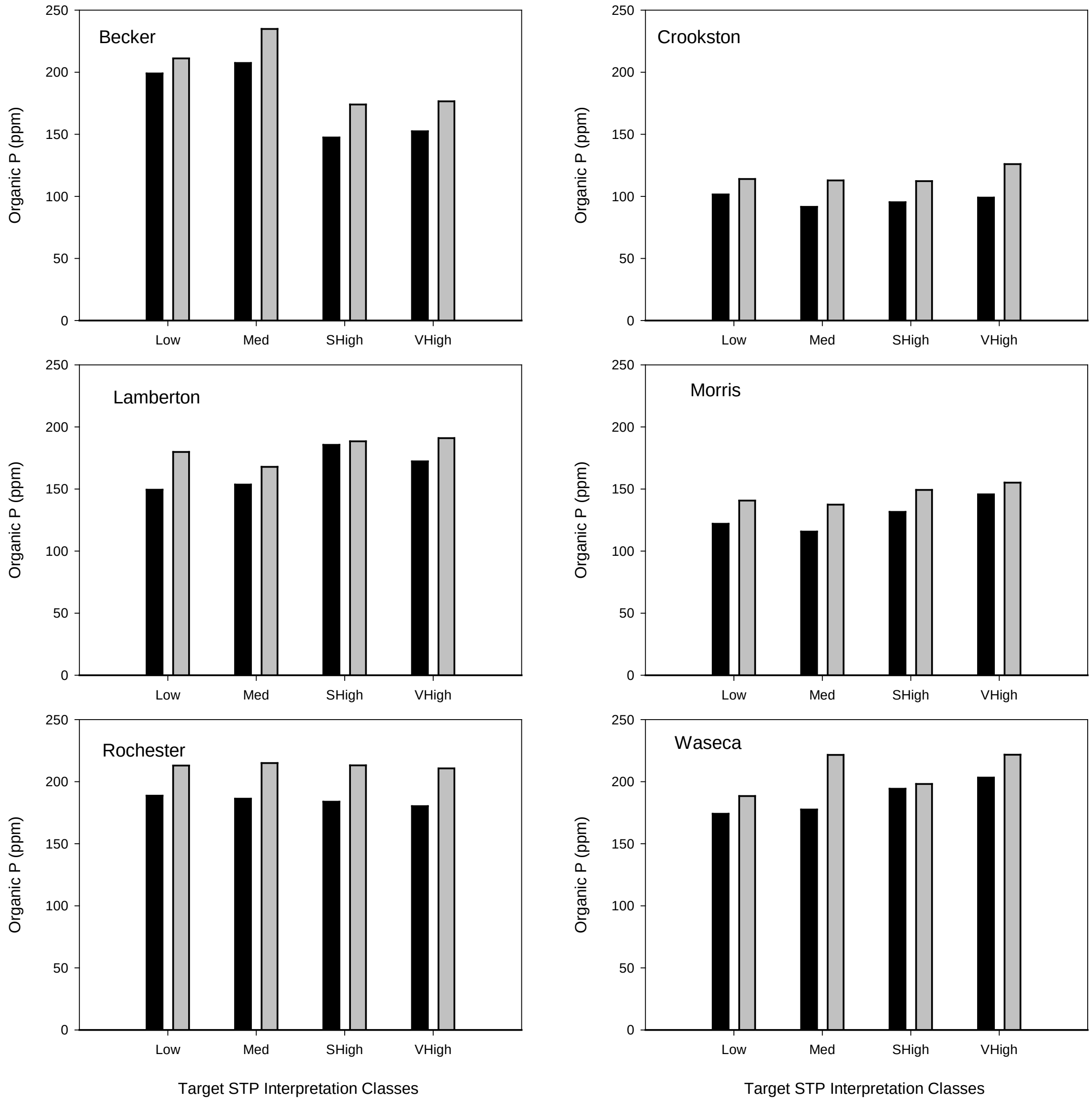


Figure 11. Total Organic phosphorus (P) changes in the 0-6 inch soil depth from the initiation of phase I (Fall 2010: black bars) to the completion of phase I (Fall 2014: gray bars) as affected by the target STP Interpretation Class.

Table 1. Soil characteristics of each experimental site

Site	Soil Series	pH	CCE	O.M.
			%	%
Becker±	Hubbard ls	5.2	0.1	1.4
Lamberton	Normania l	5.4	0.2	3.4
Rochester*	Port Byron & Mt Carroll silt loam	7.5	0.5	4.3
Waseca	Nicollet & Webster clay loam	6.0	0.1	4.7
Morris	Dolan sl	7.6	1.5	3.9
Crookston§	Gunclub Si cl	8.1	2.5	4.8

± Becker site was limed in 2012 to bring soil pH up to 5.8.

* Rochester site was limed just prior to the initiation of the experiment.

§ Crookston and Morris typically use the Olsen STP for P fertilizer recommendations.

Table 2. Statistical analysis of the average corn grain yield for the 2015 and 2016 growing season at each experimental site.

	Average Corn Grain Yield (bu ac^{1})					
Site	**Becker**	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
			……………P values……………..			
STP Class (C)	0.0481	0.3202	0.0032	0.3952	0.1435	0.3381
P (+P vs -P)	<.0001	0.0146	0.0001	0.1644	0.0396	0.2996
C x P	<.0001	0.2919	0.0092	0.1754	0.0032	0.577
Slice Effects			**……………P values……………..**			
Low	<.0001	-	<.0001	-	0.0001	-
Medium	<.0001	-	0.0408	-	0.1641	-
High	0.5838	-	0.073	-	0.2756	-
Very High	0.4948	-	0.7726	-	0.8418	-

Table 3. Statistical analysis of the average corn P removal for the 2015 and 2016 growing season at each experimental site.

	Corn P removal (lbs P_2O_5 ac[1])					
Site	**Becker**	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
			……………P values……………..			
STP Class (C)	0.0285	0.0713	0.0005	0.0002	<.0001	0.0471
P (+P vs -P)	<.0001	0.0079	<.0001	<.0001	<.0001	0.0123
C x P	<.0001	0.1451	<.0001	0.0132	<.0001	0.1341
Slice Effects			**……………P values……………..**			
Low	<.0001	-	<.0001	<.0001	<.0001	-
Medium	<.0001	-	<.0001	0.0020	0.0020	-
High	0.0585	-	0.3076	0.4434	0.1590	-
Very High	0.3713	-	0.4884	0.4953	0.2806	-

Table 4. Statistical analysis of the soybean yield for 2017 growing season at each experimental site.

	Soybean Yield (bu ac^{-1})					
Site	**Becker**	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
			……………P values……………..			
STP Class (C)	0.5400	0.0027	0.0002	0.6877	0.7698	0.4144
P (+P vs -P)	0.3362	<.0001	<.0001	0.5255	0.8934	0.8651
C x P	0.1145	0.0452	0.0002	0.5282	0.3028	0.1487
Slice Effects			……………P values……………..			
Low	-	<.0001	<.0001	-	-	-
Medium	-	0.0113	0.0004	-	-	-
High	-	0.1307	0.0131	-	-	-
Very High	-	0.1679	0.8058	-	-	-

Table 5. Statistical analysis of the soybean P removal for 2017 growing season at each experimental site.

	Soybean Grain P removal (lbs P_2O_5 ac $^{-1}$)					
Site	**Becker**	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
			…………..P values……………..			
STP Class (C)	0.0109	0.0007	0.0001	0.0188	0.1715	0.0342
P (+P vs -P)	0.0212	<.0001	<.0001	0.0004	0.0414	0.5760
C x P	0.0054	<.0001	<.0001	<.0001	0.1849	0.0336
Slice Effects			**…………..P values……………..**			
Low	0.0002	<.0001	<.0001	<.0001	-	0.0096
Medium	0.7936	<.0001	0.0001	0.0052	-	0.3397
High	0.1704	0.2575	0.0792	0.1875	-	0.2014
Very High	0.4905	0.1657	0.4110	0.1546	-	0.6823

Table 6. Percentage of protein for soybean 2017 growing season at each experimental site.

		Protein (%)					
Site		**Becker**	**Lamberton**	**Rochester**	**Waseca**	**Morris**	**Crookston**
Low	**-P**	36.1	35.4	35.1	34.6	34.1 b	32.6 c
	+P	36.3	35.7	34.6	34.7	34.5 ab	33.8 a
Medium	**-P**	35.7	35.6	34.8	34.5	34.4 ab	33.2 bc
	+P	35.6	35.3	34.8	34.4	34.0 b	33.3 ab
High	**-P**	36.1	36.0	34.8	34.1	34.1 b	33.2 abc
	+P	36.6	35.8	34.7	34.4	34.7 a	33.1 bc
V.High	**-P**	35.9	35.9	34.8	34.3	34.2 ab	33.4 ab
	+P	35.9	36.4	34.6	34.2	34.1 b	33.3 ab
		…………………………*P* values……………………………………..					
STP Class (C)		0.0021	0.1028	0.6049	0.1402	0.7964	0.7379
P (+P vs -P)		0.1123	0.8296	0.0155	0.8583	0.2942	0.0846
C x P		0.1998	0.4436	0.1367	0.6863	0.0786	0.0234

Table 7. Percentage of oil for soybean 2017 growing season at each experimental site.

		Oil (%)					
Site		**Becker**	**Lamberton**	**Rochester**	**Waseca**	**Morris**	**Crookston**
Low	**-P**	16.8	17.9	17.3	17.6 a	17.2	16.9 a
	+P	16.8	17.5	17.4	17.2 c	17.0	16.3 bc
Medium	**-P**	16.9	17.7	17.3	17.4 bc	17.1	16.4 b
	+P	16.9	17.7	17.4	17.5 ab	17.1	16.3 bc
High	**-P**	16.7	17.6	17.4	17.5 ab	17.0	16.5 ab
	+P	16.4	17.6	17.6	17.5 ab	17.0	16.2 bc
V.High	**-P**	16.8	17.8	17.7	17.4 abc	16.9	16.0 c
	+P	16.9	17.7	17.4	17.5 ab	17.0	16.3 bc
		**…………………………..*P* values…………………………………….. **					
STP Class (C)		0.0295	0.3708	0.2124	0.2121	0.5170	0.1295
P (+P vs -P)		0.3298	0.1382	0.6361	0.4519	0.6602	0.2105
C x P		0.2477	0.2455	0.1968	0.0119	0.7429	0.0750

Table 8. Phosphorus applied as fertilizer and phosphorus removed in the harvested grain over the period of 2011 to 2014 at each of the six sites for the Minnesota Long Term Phosphorus Trial.

	Low			Medium			High			V. High		
Site	**P in**	**P out**	**Diff.**	**P in**	**P out**	**Diff.**	**P in**	**P out**	**Diff.**	**P in**	**P out**	**Diff.**
	----------- lbs. P ac^{-1} ----------											
Becker	0	53.5	-53.5	44.0	71.6	-27.6	87.1	78.0	9.2	132	80.8	51.2
Crookston	0	43.3	-43.3	66.0	53.5	12.5	118.8	58	60.8	178.2	58	120.2
Lamberton	33	52.5	-19.5	99	60.9	38.1	110.4	63.9	46.5	148.3	67.8	80.5
Morris	0	54.1	-54.1	64.7	63.5	1.2	128.5	70.9	57.6	194.5	79.1	115.4
Rochester	0	82.4	-82.4	47.5	90.1	-45.6	88.9	94.6	-5.7	136.4	96.7	39.7
Waseca	0	51.8	-51.8	50.2	66.8	-16.6	92.4	72.1	20.3	135.5	75.1	60.4