**Minnesota Long-Term Phosphorus Management Trials: Phase 1, the Build Period**

**MDA Contract # 75721; SPA #00041153**

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Phosphorus fertilizer management in Minnesota is based on one of two philosophical approaches, Build and Maintain (B&M) and Sufficiency. Field research in the 1970s and 1980s suggested the Sufficiency approach applied less P fertilizer than the B&M approach while grain yields were similar indicating greater profitability with the Sufficiency approach. In recent years, it is argued that higher fertilizer applications associated with the B&M approach are necessary to obtain and maintain greater production levels in today's agricultural systems. The concern is that the Sufficiency approach will not maximize yield potential.

At the heart of both approaches is the soil test phosphorus (STP). The STP is the result of an analytical laboratory chemical procedure that extracts P from a soil sample. Many extraction procedures have been developed, but in Minnesota the Bray P1 and Olsen sodium bicarbonate extractions are most commonly used. The amount of P extracted with these procedures is the STP. Soil P chemistry is very complex and P tends to migrate back and forth through various soil chemical P pools that vary considerably in their solubility and, thus, their availability to the crop. The STP procedure represents an index value related to, but not a direct measure of, the relative quantity of P available to the crop in various soil chemical P pools. Intensive research in the 1950s and 1960s correlated STP to crop response to applied P fertilizer. The greater the STP the lower the probability the crop responded to the addition of fertilizer. Field experiments were also conducted to calibrate STP with the amount of P fertilizer necessary to optimize yields. These experiments were referred to as Correlation and Calibration experiments, respectively, and required large inputs of resources and time. The intensity of these types of experiments diminished in recent decades due to lack of funding and higher priority topics. However, most nutrient management researchers include some aspect of calibration, and sometimes correlation, in research trials designed for other purposes. This new data becomes the basis for fertilizer recommendation updates in modern agricultural systems. The drawback to this methodology is that specific questions go unanswered and hypotheses developed from existing data and known soil P chemistry are never tested. The result is ambiguity and disagreement about P fertilizer recommendations and no mechanism to conduct adequate research. In today's environmentally conscience society, agriculture cannot leave these questions to personal conjecture; rather they need to be addressed directly.

Both P fertilizer management philosophies use STP as their primary focus, but they use it differently. The B&M approach recommends P fertilizer quantities needed to build the 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. The number of years and amounts of P fertilizer required to reach the critical STP level will depend on growers' finances and situation, difference between current and target STP, soil chemistry, and crop production level. Once the target STP level is reached, annual applications of P fertilizer 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.

The merits and faults of one approach verses the other have implications on sustainable agricultural production and environmental quality. Natural soil chemistry creates uncertainties in both approaches. Phosphorus can become chemically unavailable for crop uptake over time, but the time and intensity of that behavior greatly depend on the soil's chemical characteristics. 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. However, a fundamental and practical question needs to be addressed; Is the maximum yield potential greater or similar in the B&M approach where there is little, if any, economic return for annual fertilizer applications compared to the Sufficiency approach where there is generally an economic return for annual fertilizer applications?

The purpose of these trials was to establish long-term experiments that could be used to test phosphorus management strategies on soils with a defined long-term phosphorus history. In this initial phase of the experiment we are attempting to establish plots with four different STP levels on which other management strategies can be tested and evaluated. This means some plots will have a long history of excess P fertilizer applied relative to what is removed in the crop and some plots will have substantially less P fertilizer applied than is removed in the crop. From a long-term sustainability standpoint, it is important to better understand what pools of soil P are serving as a sinks and what pools are serving as a source of P depending on an excess or deficiency of P fertilizer application. While it is beyond the scope of this experiment to identify specific soil P compounds, there is a sequential fractionation procedure that can separate soil P into pools with varying degrees of solubility which is directly related to plant availability.

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 1 is the establishment of the long-term trials starting in the fall of 2010 and terminating in the fall of 2014 when Phase 2 will begin. In Phase 1, the overall objective is to establish experiments with STP interpretation classes ranging from Low, Medium, High, and Very High developed (built) over a period of four growing seasons (2011-2014). Ultimately we want to determine if maximum yield potential differs in soil systems managed with B&M or

Sufficiency strategies, but the B&M treatments must be established first. More specifically the objectives are:

1. Establish within the same experiment, four STP interpretation class levels at six locations throughout Minnesota (Build period).

2. Monitor STP levels and determine changes in soil P within defined soil P chemical fractions at various soil depths during the Build period. This information will define differences in time and amount of P fertilizer needed to build STP levels at the various locations. In addition, P in defined soil P chemical fractions at various soil depths will monitor where P is located both chemically and physically during this Build period.

3. Monitor crop biomass, P uptake, and yield across various STP interpretation class treatments during the Build period. Evaluate crop response to the STP levels during the establishment period.

**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). 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. Split-plots were immediately delineated, but not split-plot treatments will be applied until the beginning of Phase II in the fall of 2014.

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, initiating in 2010 and continuing through 2014. Soil samples were dried, ground, and shipped to Agvise Laboratories to be analyzed for STP using three different methods: Olsen P, Bray P1, and Mehlich III.

P fertilizer was applied to each split-plot in the fall of each year at a rate that was determined by the STP level and the target Interpretation class for the whole plot in which the split-plot resided. Results from successive years represent the progress towards the objective of establishing whole plots with the targeted STP levels. The STP Interpretation Classes targeted in the whole plots are Low, Medium, High, and Very High. While these class names will be used throughout the report, the reader is reminded that these are treatment identifications only and may not be where the actual STP level is at this time. The treatment identification represents the targeted STP Interpretation Class we want to achieve over the Phase I period.

In all years, certain protocols such as tillage and crop rotation varied among the sites due to their geographic locations and cropping system typical of those locations. From 2011 through 2013, corn was grown on all the sites except Crookston where the crop rotation was Corn in 2011, soybean in 2012, and hard red spring wheat in 2013. In 2014 all sites were planted with soybean.

Whole plant tissue samples were taken at all experimental sites at the R6 development stage of corn, R6 development stage of soybean, and soft dough stage of wheat to determine the biomass and tissue P concentration. At harvesting, grain yield was determined and corrected for soil moisture content accordingly. A subsample of grain was taken to measure grain P concentration. Tissue and grain samples were sent to Agvise to measure P concentration in tissue and grain, respectively. Grain P removal was determined from grain yield, and grain P concentration.

Soil characteristics of each experimental site are presented in Table 1.

## Summary Results

### ***Interpretation Class***

The results presented in this report are a composite of all the major measured variables throughout the trial period to this point in time. Figure 1 to 6 illustrates the development of and the current status of the Whole plot STP Interpretation Class at each experimental site. The figures include the Olsen P test for Crookston and Morris because both of these sites are considered calcareous or high pH soils. For all other sites the Bray P1 soil test is illustrated because these sites tend to have lower or acidic soil pH.

In the Low class, no P fertilizer has been applied to these plots since before the beginning of the trial. Soil test P levels have declined in the Low treatments over the duration of this trial (Fig. 1,2,4,5,6). This is probably the result of continuous removal of P in the harvested grain and no addition of fertilizer P. The exception to this is at Lamberton where the Low treatment seems to have increased in STP over the duration of this trial (Fig. 3). At this time, this tendency at Lamberton is difficult to explain.

In the Medium class, there appears to be little change in STP over time at some locations, Rochester and Waseca and possibly Crookston (Fig. 2, 5,6). At Morris and Becker there may be a tendency for STP levels to be decreasing (Fig.1,4). And again at Lamberton, STP levels have increased over the duration of this experiment. Where STP levels have not changed the amount of fertilizer P applied must be offsetting the amount of P removed in the harvested grain. Declining STP levels may be suggesting that the fertilizer P applied is insufficient to maintain STP.

Both the High and V. High STP levels tend to increase over the duration of this experiment. This suggests fertilizer P applications might be exceeding the need based on what the crop removes and that the difference between the two higher STP Interpretation Classes is the degree to which the fertilizer P exceeds crop removal.

At the end of Phase I in 2014, all sites had reached significant differences among the four established interpretation classes: Very High >High> Medium>Low class ($P<.0001$) (Fig.1 to 6). This trial is ready to enter into Phase II in the fall of 2014. All the target Interpretation Classes have been reached. In some cases they may have actually been exceeded by some small margin. Fertilizer P applications have been continuously modified to fit the immediate need to achieve the objectives. Nevertheless, it is clear that we have obtained a range of STP Interpretation Classes by which to test the objectives of Phase II.

***Grain Yield***

Grain yield through the duration of these experiments for each experiment are illustrated in Figure 7 to 11.

A Becker, in the first growing season of the trial (2011), corn yield was similar between the VHigh and High treatments which were significantly greater than the Medium and Low treatment which were similar to each other (Fig. 7). No differences were detected during the 2012 corn growing season, however the Low class tend to be lower than the rest of the Soil Interpretation Classes. For 2013 corn growing season yields were similar among VHigh, High and Medium and all were significantly higher than Low STP treatments. During 2014, soybean yields at VHigh were similar to High but significantly greater than Medium and Low treatments (Fig.7).

At Crookston 2011, VHigh and High classes had similar corn yields than Medium treatment, but had significantly greater corn yields than Low classes (Fig. 8). In 2012 and 2013, soybean and hard red spring wheat yields were similar among all the soil interpretation classes (Fig. 8). In 2014 soybean yields were similar among the VHigh, High and Medium class and all significantly greater than Low class (Fig.8).

At Lamberton, corn grain yields had no significant differences among STP classes in the three growing seasons (2011, 2012, 2013) (Fig.9). However in 2014, soybean yields differences were detected between the Low and all other Interpretation classes (Fig 9).

At Morris, corn yields were not significant different among soil interpretation classes during 2011 and 2012 (Fig. 10), although there is a slight trend of increasing yield with increasing soil test or Interpretation Class, especially in 2012. In 2013 corn yields were similar in the VHigh and High treatments, but VHigh was significantly greater than

Medium and Low soil class P (Fig. 10). No significant differences on soybean yields were detected in 2014 (Fig.10).

At Rochester site, first 2 corn growing season had shown grain yield response to soil test classes, however no differences were detected in 2013 (corn) and 2014 (soybean). Corn grain yields were similar among High and VHigh, but High treatments were significantly greater than the Medium and Low treatments in 2011 (Fig. 10). In 2012, corn grain yields were similar between VHigh and High, but VHigh class had significantly greater yields than Medium and Low interpretation class (Fig. 10).

At Waseca site, similar response was observed in all the evaluated years. Corn or soybean yields were similar among VHigh, High and Medium soil interpretation classes and all had significantly greater yields than Low treatments (Fig.11).

***Grain Removal of P***

Grain P removal was very responsive to the level of applied P or the target Soil Test P Interpretation Class (Figure 7 to 12). At all locations, as the Interpretation Class went from Low to High or Very High, the amount of P removed in the grain also increased. Since grain yields did not increase in the same manner, the grain P concentration must have been very responsive to the increased availability of P in those treatments with higher rates of fertilizer P or those that had been developed to have a higher Soil Test P level.

At Becker, grain P removal differences among soil test P classes were more pronounced in the last 2 years of Phase I, where VHigh and High classes were similar and significantly greater than Medium and Low STP classes (Fig. 7).

At Crookston, similar response of grain P removal was observed for corn (2011), soybean (2012) and hard red spring wheat (2013). Grain P removal was similar among VHigh, High and Medium and all were significantly greater than Low treatments (Fig 8). In 2014, grain P removal for soybean was significantly higher in the VHigh than Medium and Low treatments. High treatments were similar to V.High and Medium, but significantly greater than Low (Fig.8).

At Lamberton, only in 2011 significant differences were detected in the amount of grain P removed, the Medium, High and V.High removed greater amount of P than Low treatments (Fig. 9). In 2012 and 2013, no differences were detected but there is a trend to greater removal with the increase on soil test P class (Fig.9). Grain P data for 2014 is still under processing.

At Morris, each year showed a significant response of grain P removal to the increase in soil test P class (Fig. 10). In 2012 and 2013, grain P removal in the V.High was similar to High treatments but significantly greater than Medium and Low STP. In 2014, VHigh and High had similar soybean grain P removal but was lower than Low treatments.

At Rochester, grain P removal was similar among STP classes in 2011, but showed differences in the other years. In 2012, corn grain P removal was greater in the VHigh than Medium and Low, but similar to High STP class (Fig. 11). In 2013, corn grain P removal was similar between VHigh and High, but High had significantly greater grain P removal than Medium and Low. Soybean P removal in 2014 was similar among Medium, High and V.High, but significantly greater than Low STP class (Fig 11).

At Waseca, during corn growing season 2011 and 2013 similar grain P removal was observed among the V.High, High and Medium and all were significantly greater than Low STP class (Fig.12). In corn 2012, High and V.High had significantly greater corn P removal than Medium and Low treatments (Fig.12). Soybean grain P removal was greater under V.High than Medium and Low, but similar to High STP class (Fig, 12).

**Table 1. Soil characteristics of each experimental site**

| | STK | pH | CCE | SOM |
|---|---|---|---|---|
| | ppm | | % | % |
| **BECKER** | 72.4 | 5.2 | 0.1 | 1.4 |
| **CROOKSTON** | - | 8.1 | 2.5 | 4.8 |
| **LAMBERTON** | 120.7 | 5.4 | 0.2 | 3.4 |
| **MORRIS** | 176 | 7.6 | 1.5 | 3.9 |
| **ROCHESTER** | 164.4 | 7.5 | 0.5 | 4.3 |
| **WASECA** | 188.6 | 6.0 | 0.1 | 4.7 |

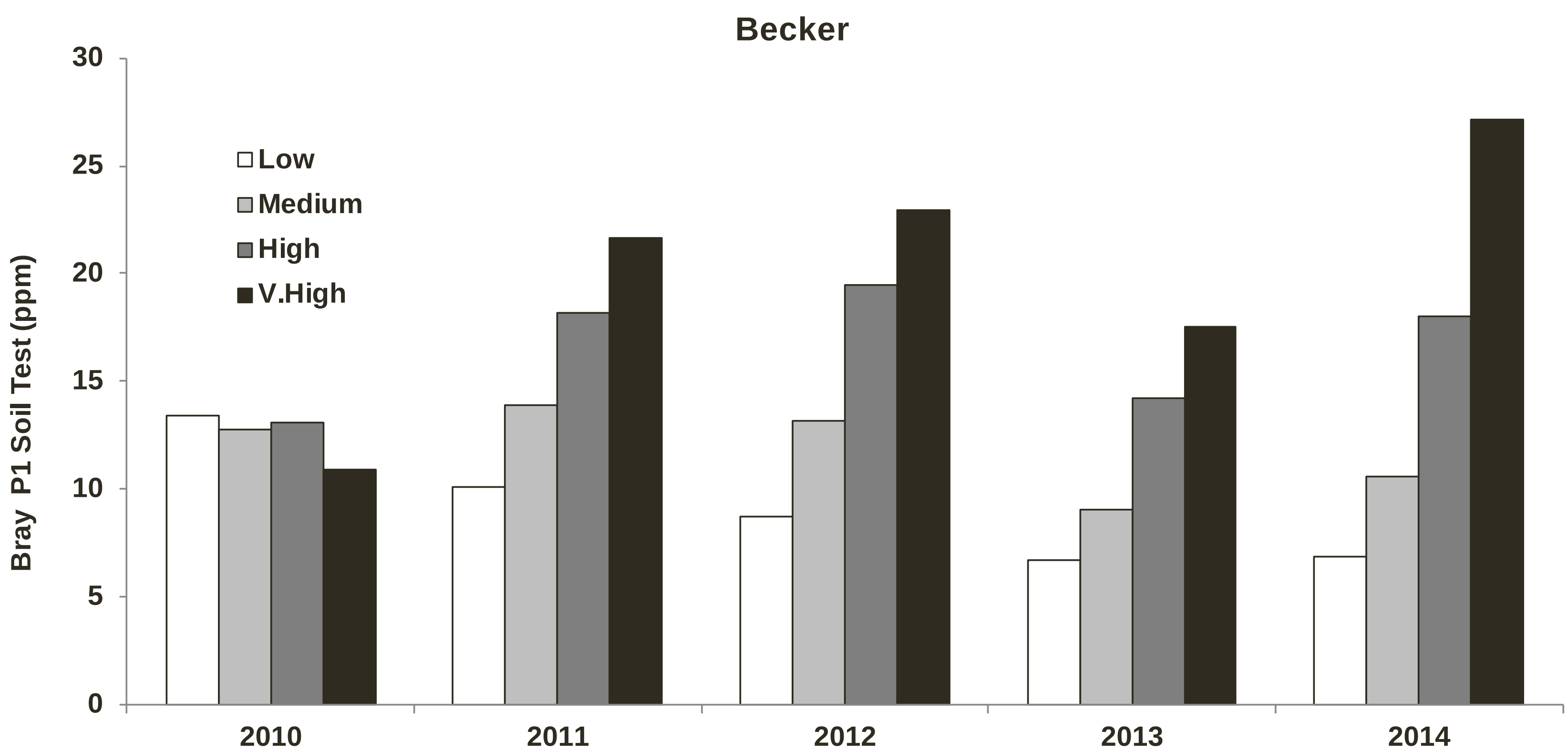


**Figure 1. Soil test phosphorus (Bray-P1) from 2010 through 2014 at Becker site.**

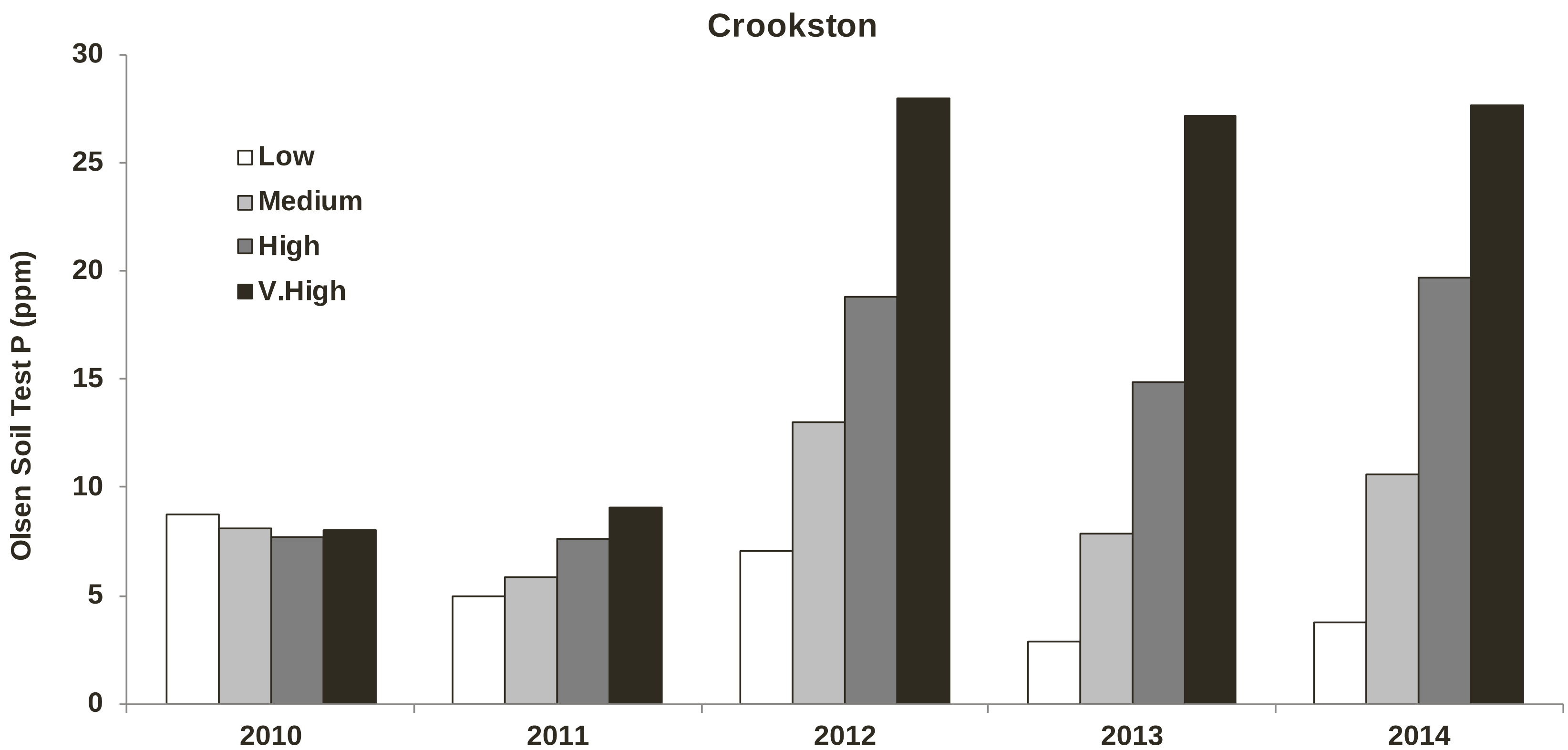


**Figure 2. Soil test phosphorus (Olsen-P) from 2010 through 2014 at Crookston site.**

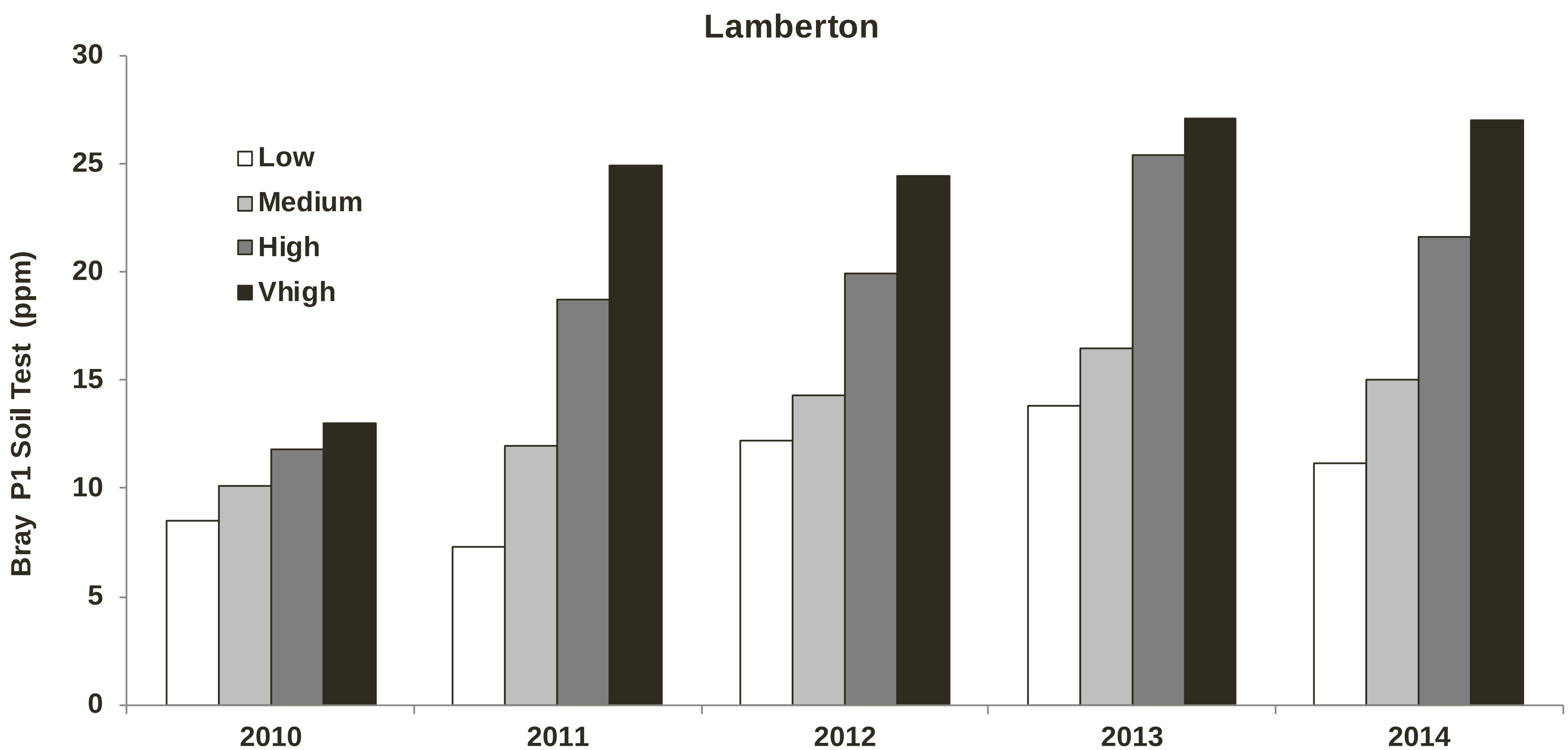


**Figure 3. Soil test phosphorus (Bray-P1) from 2010 through 2014 at Lamberton site.**

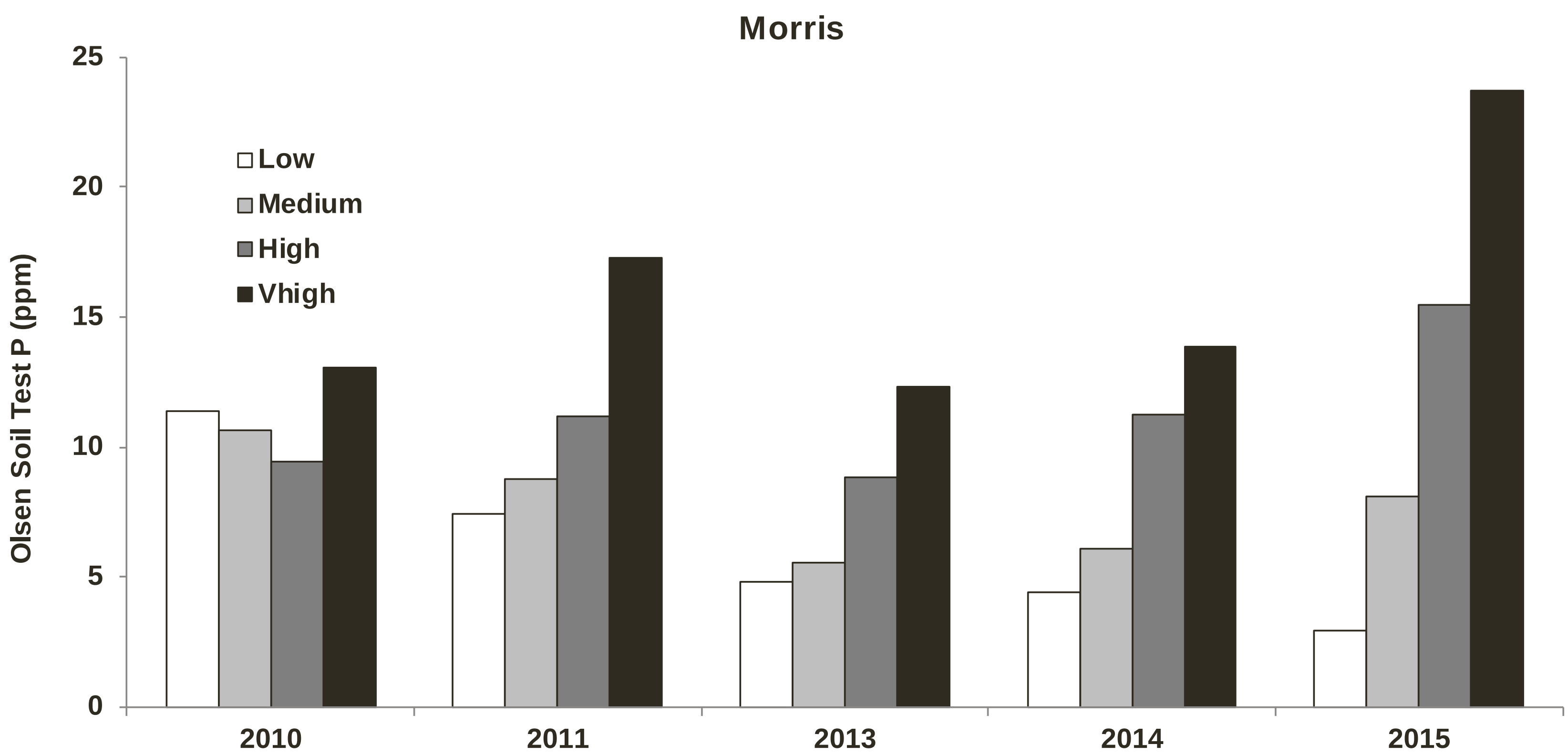


**Figure 4. Soil test phosphorus (Olsen-P) from 2010 through 2014 at Morris site.**

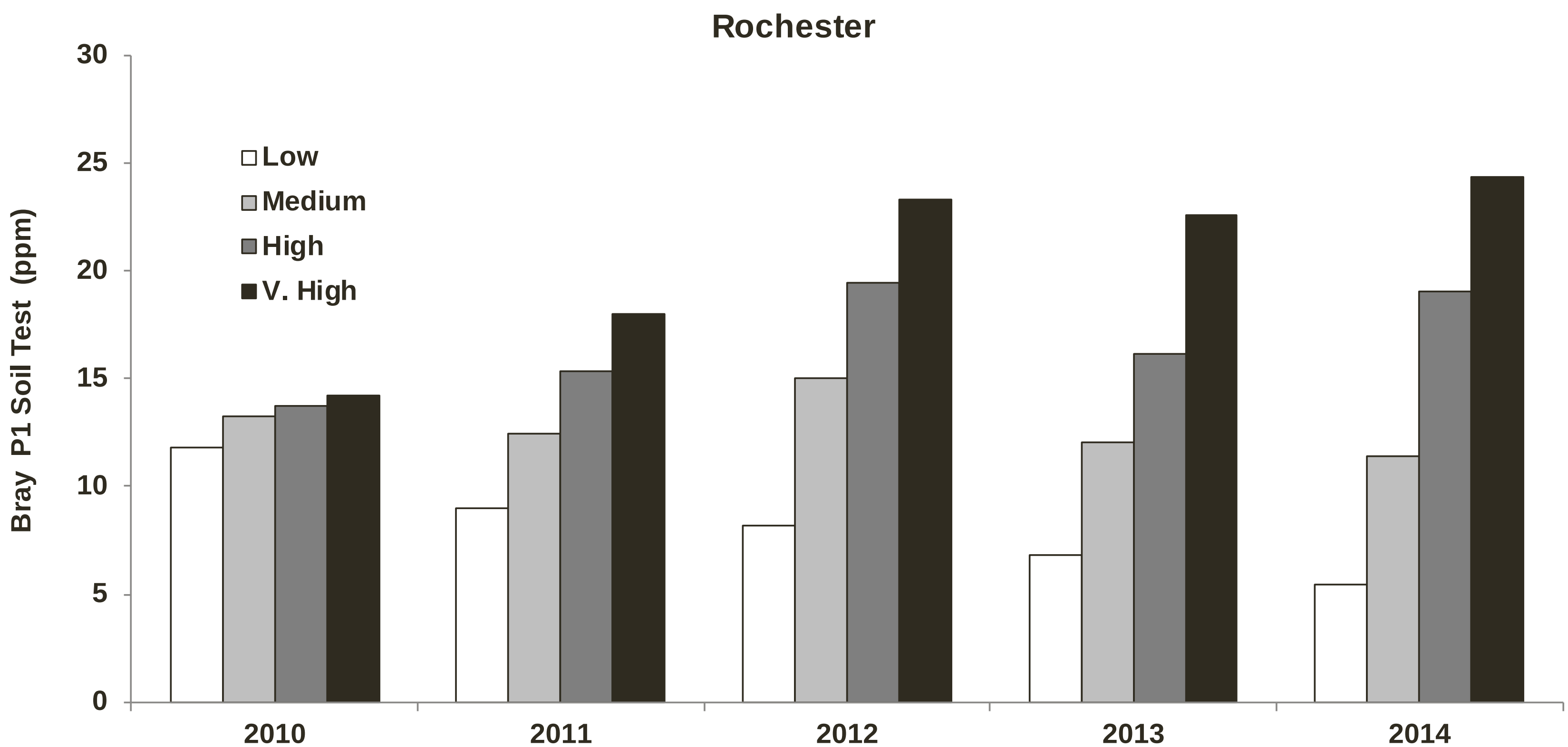


**Figure 5. Soil test phosphorus (Bray-P1) from 2010 through 2014 at Rochester site.**

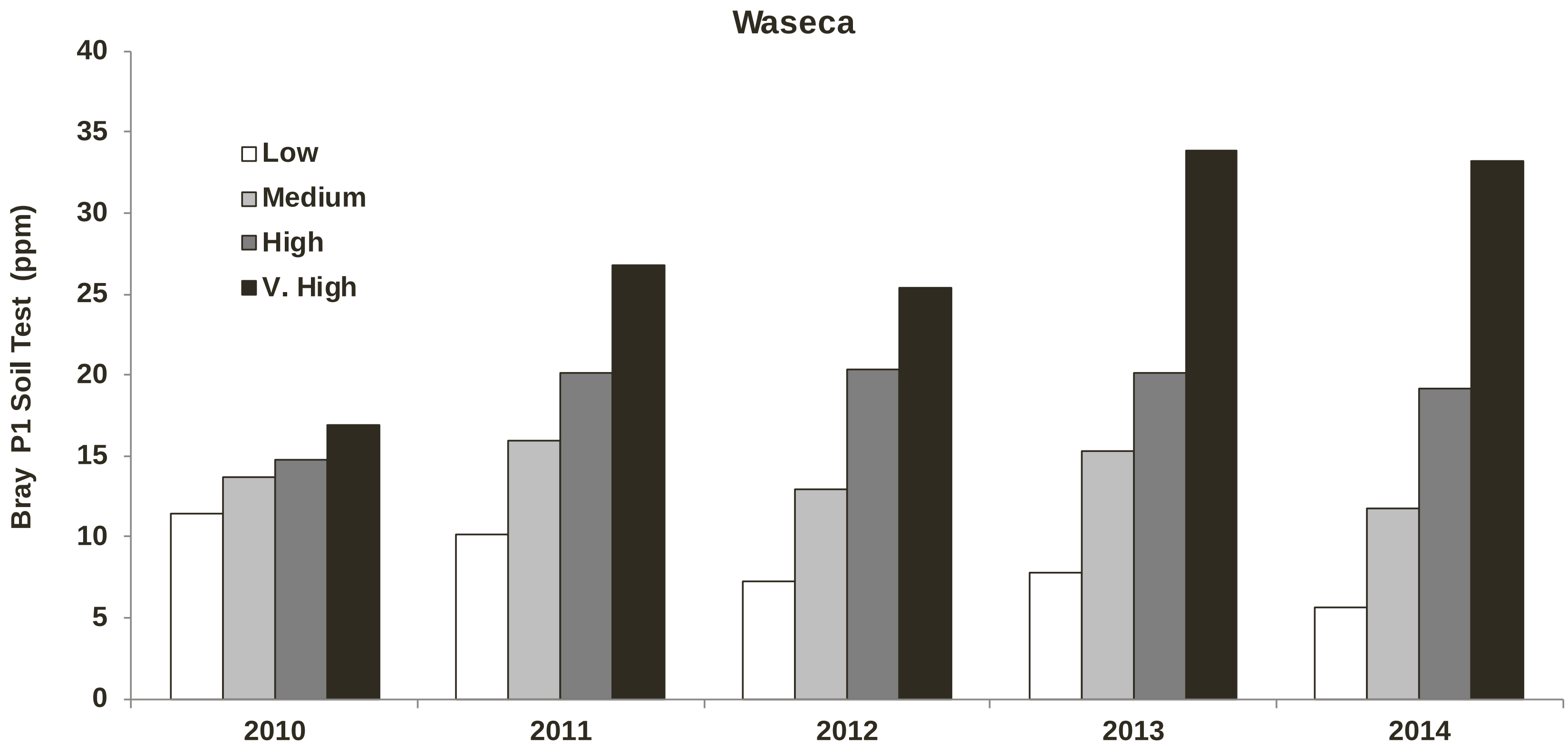


**Figure 6. Soil test phosphorus (Bray-P1) from 2010 through 2014 at Waseca site.**

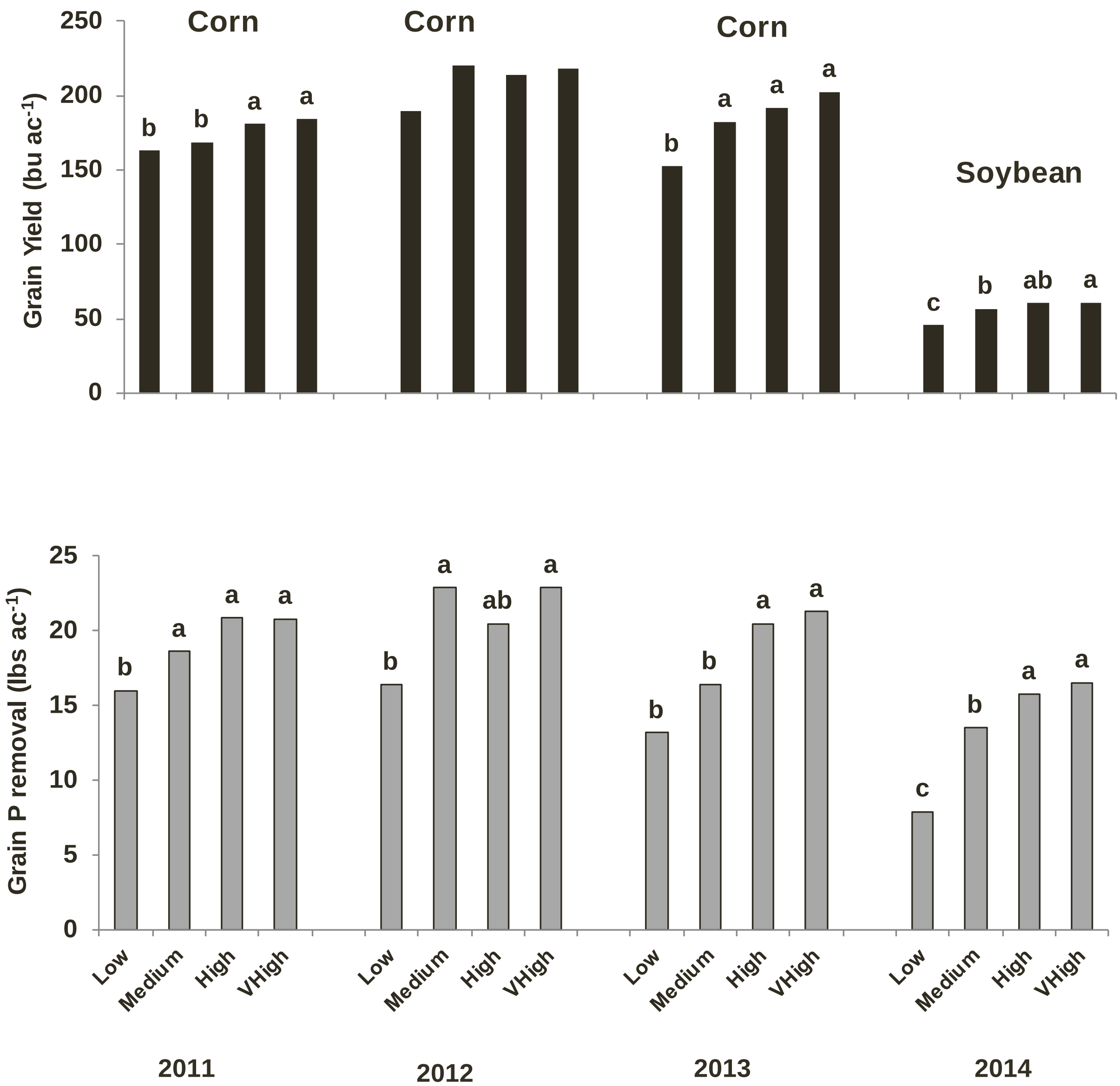


**Figure 7. Grain Yield (bu $ac^{-1}$) and grain P removal (lbs $ac^{-1}$) for each soil test P (STP) interpretation classes at Becker site from 2011 to 2014- Phase I.**

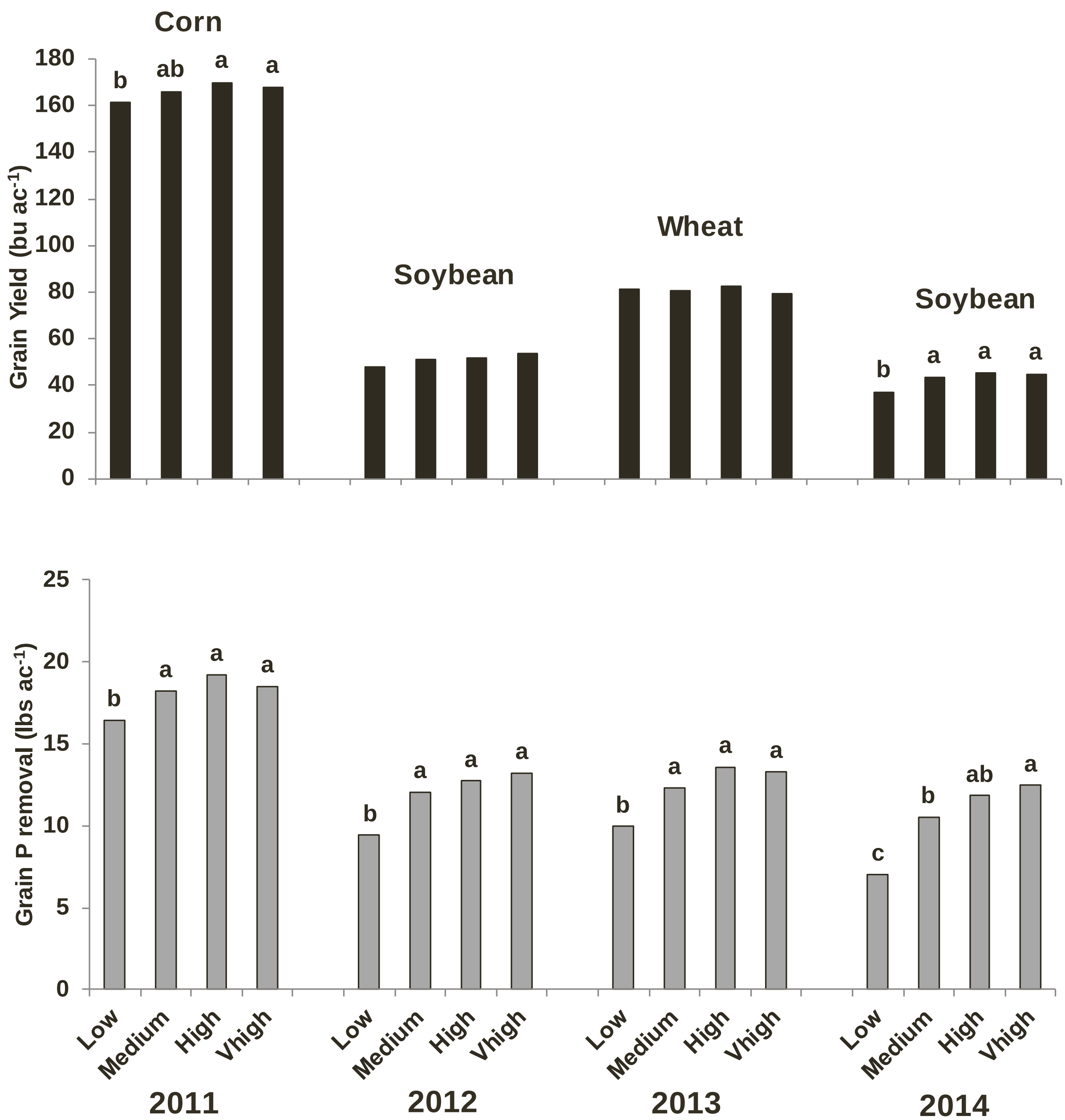


**Figure 8. Grain Yield (bu ac$^{-1}$) and grain P removal (lbs ac$^{-1}$) for each soil test P (STP) interpretation classes at Crookston site from 2011 to 2014- Phase I.**

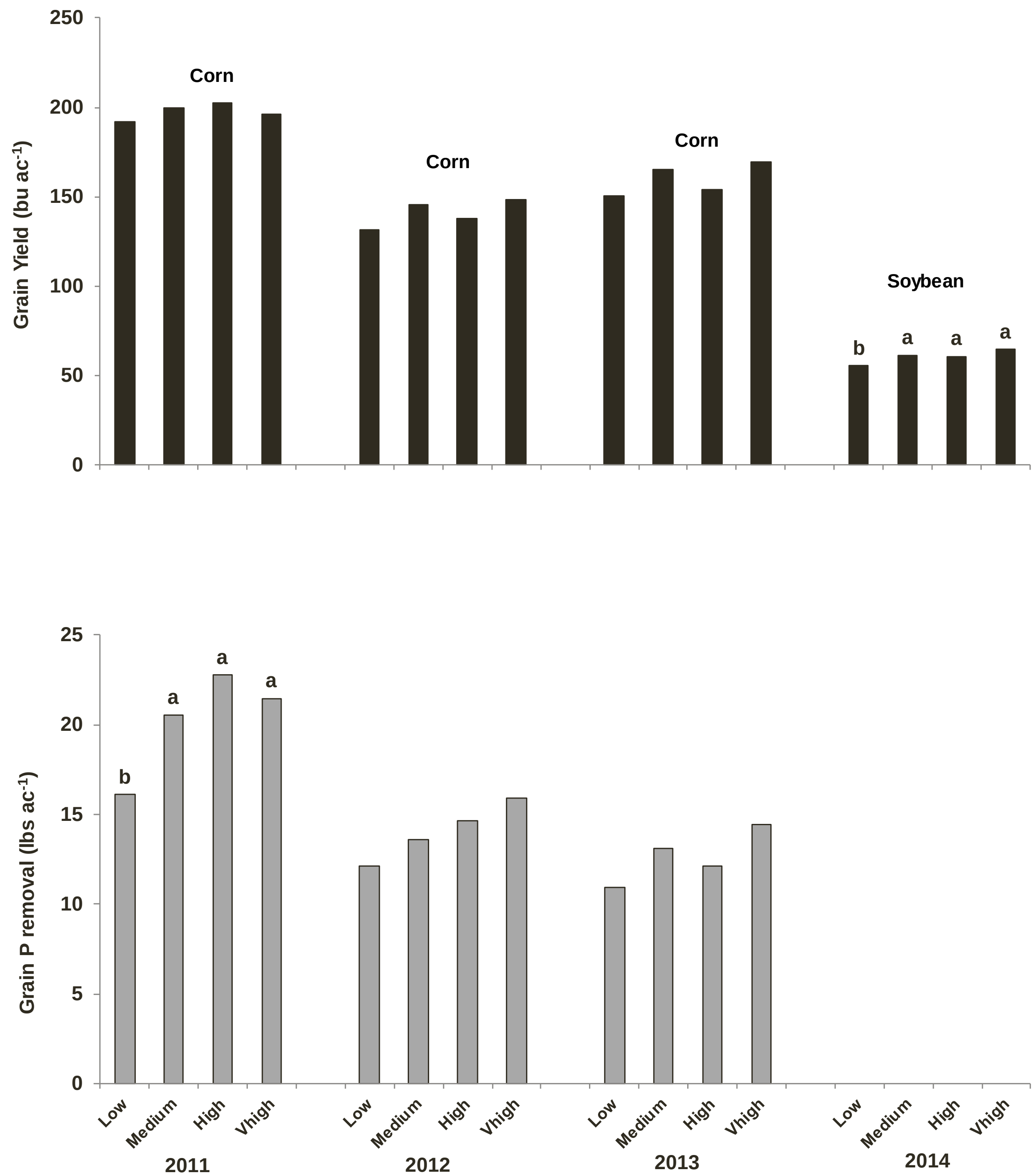


**Figure 9. Grain Yield (bu ac$^{-1}$) and grain P removal (lbs ac$^{-1}$) for each soil test P (STP) interpretation classes at Lamberton site from 2011 to 2014- Phase I.**

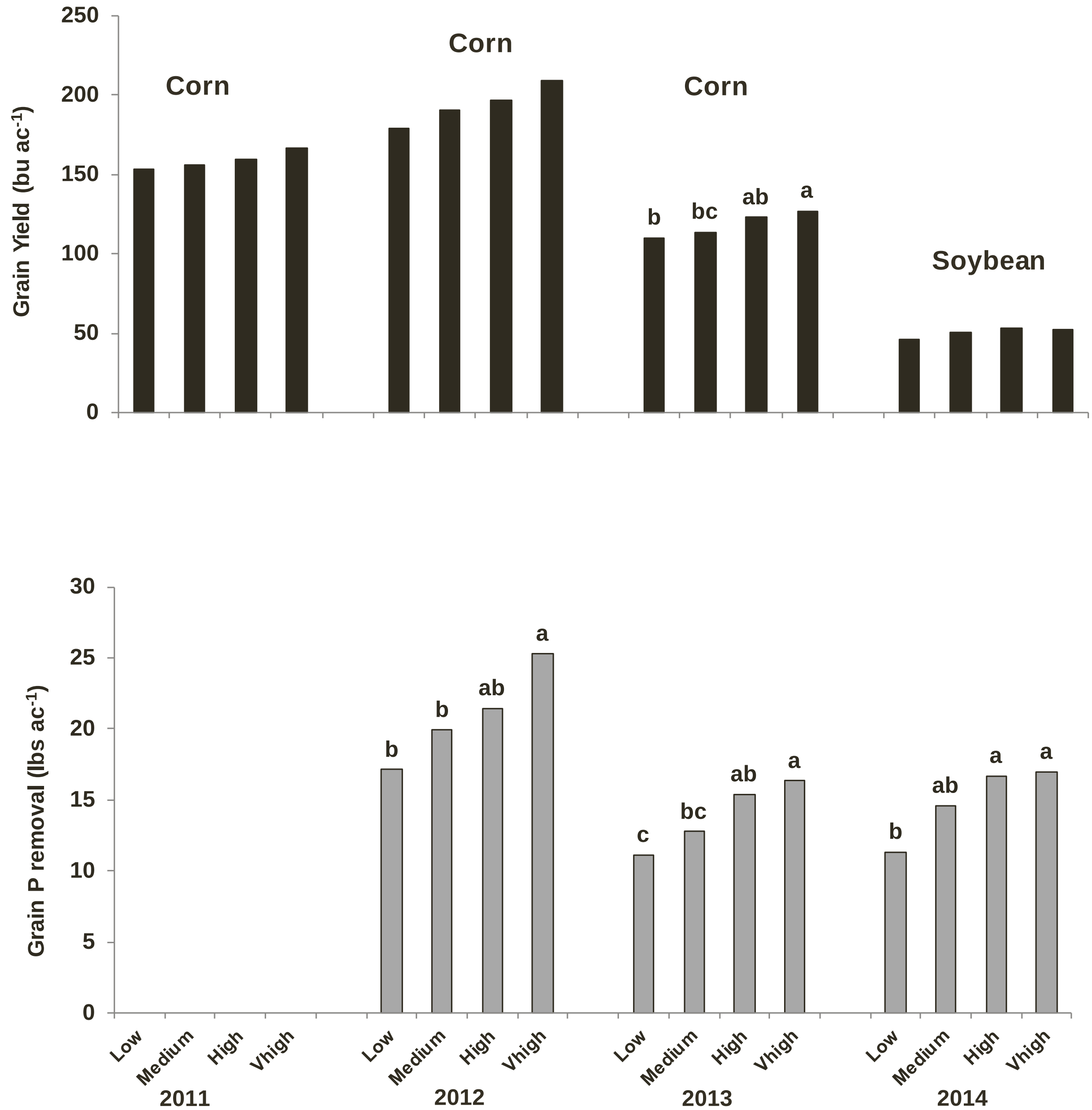


**Figure 10. Grain Yield (bu ac$^{-1}$) and grain P removal (lbs ac$^{-1}$) for each soil test P (STP) interpretation classes at Morris site from 2011 to 2014- Phase I.**

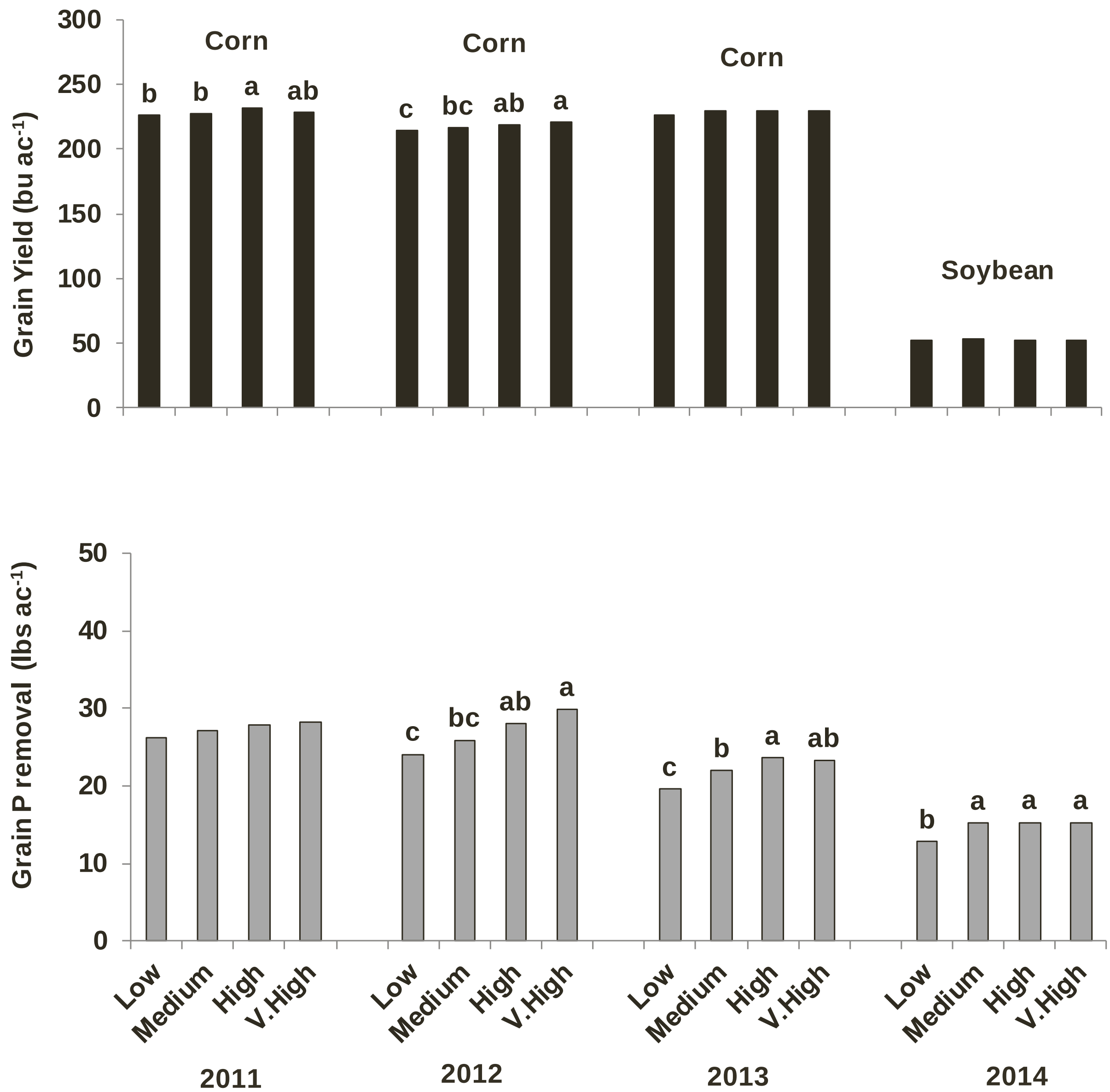


**Figure 11. Grain Yield (bu ac$^{-1}$) and grain P removal (lbs ac$^{-1}$) for each soil test P (STP) interpretation classes at Rochester site from 2011 to 2014- Phase I.**

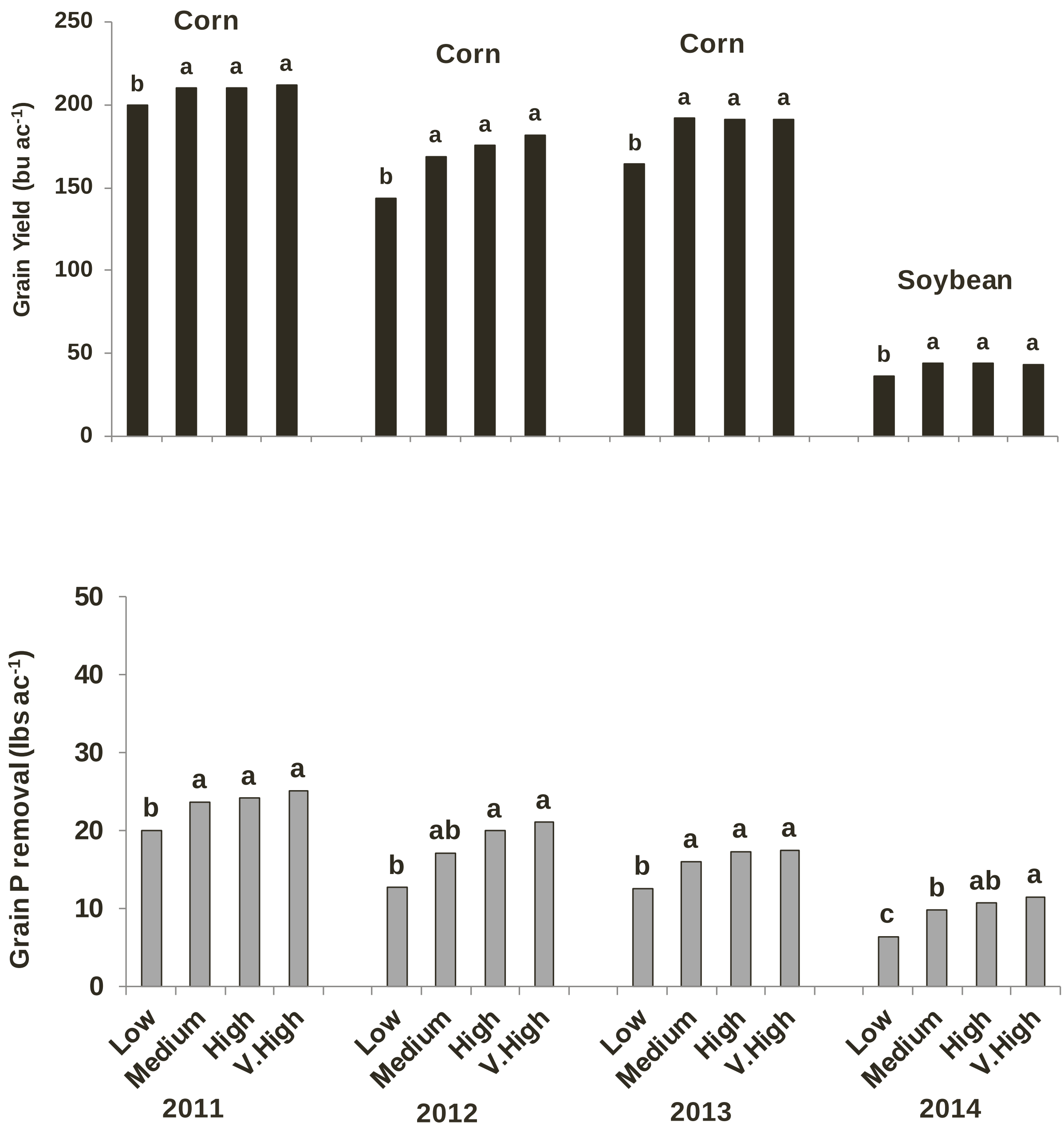


**Figure 12. Grain Yield (bu ac$^{-1}$) and grain P removal (lbs ac$^{-1}$) for each soil test P (STP) interpretation classes at Waseca site from 2011 to 2014- Phase I.**