Minnesota Long-Term Phosphorus Management Trials-Phase II: Sufficiency Level vs. Build and Maintain Approaches

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ABSTRACT

Current Minnesota P recommendations for corn and soybean are based on the Sufficiency approach. In recent years, it has been questionable that the Sufficiency approach could maximize potential grain yield in today's agricultural systems. The objective of this research was to establish six long-term experiments across Minnesota to test phosphorus management strategies on soils with a defined long-term phosphorus history. Four soil test P (STP) Interpretation Classes were established as whole plots (Low, Medium, High, and Very High) at each experimental site. Split-plots consisted one split-plot did not received P (-P), and the second split-plot received a broadcast application of P fertilizer (+P) at the rate of 150, 90, 30 and 30 lbs P_2O_5 ac^{-1} for the Low, Medium, High and Very High STP category treatments, respectively. Grain yield, grain P concentration and grain P removal were determined during 2015 and 2016 corn growing season at all sites. Overall, 3 of the 6 sites showed significant response to applied-P in the Low and Medium STP classes, but not in the High and Very High classes . Phosphours application increased grain P removal in the Low and Medium STP classes at 4 of the 6 experimental sites. Grain yield and grain P removal were similar between +P and -P treatments in the High or Very High STP classes. Results from both growing seasons showed not evidence 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 at any of the evaluated sites.

INTRODUCTION

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 higher fertilizer applications associated with the B&M approach are necessary to obtain and maintain greater production levels in today's agricultural systems. However, there is still a concern if the Sufficiency approach will maximize yield potential.

The primary goal of this project was to establish long-term field trials at several locations across Minnesota to test P management strategies. This research was developed in two phases:

- **Phase I** was the establishment of the long-term trials 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**: Evaluate corn yield and P removal response to P fertilizer as well as yield potential within each STP interpretation class.

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 (ROCs) except for one near Rochester, which has been managed as a long-term research site by the Southern ROC. 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 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).

Table 1. Soil characteristics at the six experimental sites.

		pH	CCE	OM
Site (Soil Series)	**Soil Taxonomy**	**%**	**%**	**%**
Becker±: Hubbard ls	Sandy, mixed, frigid Entic Hapludoll	5.2	0.1	1.4
Lamberton: Normania l	Fine-loamy, mixed, superactive, mesic Calcic Hapludoll	5.4	0.2	3.4
Rochester*: Port Byron & Mt. Carroll silty loam	Fine-silty, mixed, superactive, mesic Mollic Haludalf	7.5	0.5	4.3
Waseca: Nicollet & Webster clay loam	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll	6.0	0.1	4.7
Morris: Dolan sl	Fine-loamy, mixed, superactive, frigid Aquic Calciudoll	7.6	1.5	3.9
Crookston§: Gunclub Si cl	Fine-silty, mixed, superactive, frigid Aeric Calciaquoll	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

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 growing season. The remaining 2 split-plots were used during 2016 corn growing season. One split-plot did not received P (-P), and the second split-plot received application of P fertilizer (+P) at the rate of 150, 90, 30 and 30 lbs P_2O_5 ac^{-1} for the Low, Medium, High and Very High (V.High) STP category treatments, respectively. 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) for all locations except Crookston which the rotation was corn (2011)-soybean (2012)-wheat (2013)-soybean (2014)-corn (2015)-corn (2016). All agronomic practices at each location were customary for the region.

Grain yield (adjusted to 15.5% moisture), 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. Soil samples were taken from each plot to a depth of 6 inches from mid-summer to late fall or early spring, depending on the site. Soil test P was determined using three conventional methods: Olsen P, Bray P1, and Mehlich III (Frank et al., 1998).

Statistical data analysis was performed for each site using PROC GLIMMIXED procedure (SAS, Institute 2012) assuming fixed effects Soil P category, and P fertilizer application and random blocking effects.

RESULTS AND DISCUSSION

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.

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.

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**).

Table 2. Statistical analysis of Grain yield: Effect of soil test P (STP) classes, P application (+P and -P) and interactions. Average of 2015 and 2016 growing seasons.

Corn Grain Yield						
	Becker	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
STP Class (C)	0.0481	0.3202	0.0032	0.3952	0.1435	0.3381
P (+P and -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 Grain P removal: Effect of soil test P (STP) classes, P application (+P and -P) and interactions. Average of 2015 and 2016 growing seasons.

Grain P removal						
	Becker	**Lamberton**	**Waseca**	**Rochester**	**Crookston**	**Morris**
STP Class (C)	0.0285	0.0713	0.0005	0.0002	<.0001	0.0471
P (+P and -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	0.0001	-
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	-

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 the Lamberton site (**Fig. 2** and **3;**

Table 2 and **3**).

At the Waseca site, 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 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**).

At Rochester, grain yield had no significant response to applied-P (+P) for any of the STP classes (**Fig. 2, Table 2**). However, grain P removal was significantly higher in the applied-P than in the noP-applied treatments at the Low and Medium STP classes (**Fig. 3, Table 3**).

At Morris, grain yield was similar among treatments (**Fig. 2, Table 2**). Grain P removal had not significant response to applied-P (+P) in any of STP class (**Fig. 3, Table 3**).

Grain yield was significantly greater in the applied-P treatments in the Low STP class at the Crookston site (**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 no P-applied (-P) treatments in the Low and Medium STP classes (**Fig. 3, Table 3**).

Overall, 2 of the 6 sites (Becker, Crookston) and 3 of the 6 sites (Becker, Crookston,Waseca) during 2015 and 2016 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 in both growing seasons, and 4 of the 6 sites showed greater P removal with applied-P especially in the Low and Medium STP classes. 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 (+P) in the High or Very High STP classes.

CONCLUSIONS

Results from both growing seasons showed not 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. Therefore, 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 without P fertilizer applied. A Build and Maintain fertilizer approach would only result in greater input (fertilizer) costs and would not result in greater corn yields, however this aproach can provide some flexibility when fertilizer P prices increase unexpectedly.

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