MINNESOTA LONG-TERM PHOSPHORUS MANAGEMENT TRIALS: PHASE I, THE BUILD PERIOD

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Abstact

Phosphorus (P) fertilizer recommendations are usually made using one of two philosophies, Build and Maintain or Sufficiency. In recent years, the Sufficiency approach has been questioned because of concerns of reducing soil test levels and yield sustainability and whether it has the same yield potential as the Build and Maintain approach. Trials were initiated in 2010 at six locations across Minnesota to develop various soil test P Interpretation Classes in replicated experiments. The initial phase of this experiment was to develop a range of soil test P levels that would fall within the Low, Medium, High, and Very High Interpretation Classes. Phase I of this experiment has been completed and fall 2014 initiates Phase II of the experiment. Grain yield and other production variables were monitored throughout Phase I, but the real questions will be answered during Phase II when yield response to P fertilizer within each Interpretation Class will be determined as well as yield potential of that response.

Introduction

Knowing when P fertilizer is needed in a cropping system is best estimated using a soil test. In Minnesota, the two most common soil test P (STP) extraction procedures used are the Bray P-1 (Bray and Kurtz, 1945) for soils with pH of 7.4 or less or the Olsen $NaHCO_3$ (Olsen et al., 1954) for soils with pH greater than 7.4. The STP is an index estimate of the readily plant available soil phosphorus of the field or zone within the field. The STP is grouped into an interpretation class that is then used for fertilizer recommendations (Kamprath and Watson, 1980). In Minnesota, interpretation classes of very Low, Low, Medium, High, and very High are used.

The quantity of P fertilizer to apply once the STP is measured is determined by one of two philosophies, ‘Sufficiency’ or ‘Build and Maintain’ (Olson et al., 1987). In the ‘Sufficiency’ philosophy, P fertilizer quantities are determined by the current STP level and the requirements to achieve an economically optimum production level, which have been determined by calibration research. That is, the crop is fertilized such that there is a high probability a dollar or more is returned for each dollar of fertilizer applied. This philosophy relies on the soil P reserves to contribute to the crop needs. Fertilizer is a supplement to the soil’s contribution to achieve optimum crop production. In the ‘Build and Maintain’ philosophy, P fertilizer applications rates are determined by that required to raise STP to some target level, usually the critical level or that STP level at which there is very slight probability the crop will actually respond to the application of additional fertilizer. Once that target STP level is attained, annual rates of P fertilizer are applied to replace what was removed in the previous crop plus additional P that is required depending on the soil chemical characteristics, to maintain the critical STP level.

Multi-year experiments (4-12 years) in Nebraska (Olson et al. 1982; Olson et al., 1987) and similar trials in Minnesota (personal communications with George Rehm, retired Nutrient Management Extension Specialist, University of Minnesota) testing the input costs and production output of the two philosophies have shown there is no yield advantage of one verses the other, but the 'Build and Maintain' approach required significantly greater fertilizer input and costs than the 'Sufficiency' approach.

Though these studies showed no yield difference between the two philosophical approaches, some now argue that the yield levels of today are substantially higher than those in the 1970s and 1980s when these trials were conducted. These higher yields are removing greater amounts of P from the soil and P fertilizer applications have not increased to the same extent. That is, the 'Sufficiency' approach is mining soil P reserves to a greater extent at today's high yield environments. Surveys have shown a continual decline in STP levels throughout much of the intensively managed agronomic crop producing areas in the U.S. (Fixen et al, 2010). Regression analysis suggests that STP declines were due to greater P being removed in the harvested crop than was being supplied as fertilizer (Fixen et al., 2010). Theoretically in a 'Sufficiency' approach, as the STP levels decline recommended P fertilizer should be increasing. There have been some observations that yield levels are higher when STP levels have been maintained at a higher level than if it is at a lower level and annual P fertilizer applications are relied on to achieve optimum yields (personal communications with Dr. David Franzen, NDSU and Dr. John Lamb, Univ. of Minn.). This suggests that yield potential is greater using the 'Build and Maintain' approach than using the 'Sufficiency' approach in today's high yield environment. However in some cases, there is confounding evidence suggesting lower STP level areas of a field may be low yield potential areas for reasons other than STP (personal communications with Dr. John Lamb, Univ. of Minn.).

If the 'Build and Maintenance' philosophy is used, what is the cost, both financially and in P resources, to raise STP levels to a desired critical level? Research from various states in the north central U.S. has shown the amount of P fertilizer required to raise Bray I-P levels 1 ppm can vary from 9 lbs. P_2O_5 Ac^{-1} in Wisconsin (Schulte and Kelling, 1991) to 18 lbs. P_2O_5 Ac^{-1} in Illinois (Peck et al. 1971) to 53 and 41 lbs. P_2O_5 Ac^{-1} in Minnesota (Randall et al., 1997). Raising STP levels to a desired level appears to depend on a number of factors. Randall et al. (1997) found that soils responded differently partly because of the initial STP level and the amount of P fertilizer that was actually required to raise the STP level.

The large overall input costs in today's cropping systems leaves many producers wanting to ensure optimum yields for their overall inputs and not just P fertilizer input. Therefore, they are more willing to spend extra input dollars to raise STP to critical levels hoping this reduces the possibility there will ever be a yield reducing P deficiency situation. Disputing the claim of greater yield potential with the 'Build and Maintain' versus the 'Sufficiency' approach to fertilizer recommendations in today's high yield environment is difficult because there are very few direct comparisons. Side-by-side replicated trials are needed to test the question. The data that do exist (Olson, 1982) clearly show there are considerable implications in fertilizer costs and P resource input and possibly STP levels that might lead to environmental issues if not carefully managed yet there is no return value to the producer.

The overall objective of this experiment is to make direct comparisons, in terms of yield response to applied fertilizer P and ultimate yield potential, of various STP Interpretation Classes. Initially, however, the objective was develop in replicated field trials treatments that have a range of STP levels built over a four year period at six locations representing the major agronomic growing areas of Minnesota.

Methods and Materials

Six experimental sites were located at various locations across Minnesota representing the major agronomic production regions of the state (Fig 1). 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. Whole plot treatments are a range of established soil test phosphorus (STP) Interpretation Class, which were developed during Phase I of this trial (2010-2014). Split-plots were delineated at the beginning of the experiment, but no split-plot treatments were applied until the beginning of Phase II, fall of 2014.

Beginning in the fall of 2010 and proceeding each year thereafter, soil samples were collected from each trial and sent to Agvise Laboratories for STP analysis using the Olsen, Bray I, and Mehlich III methods. Phosphorus fertilizer (triple superphosphate) was applied to each split-plot based on its STP level at the time and Interpretation Class treatment targeted for the whole plot within which the split-plot resides. Targeted whole plot Interpretation Classes were Low, Medium, High, and Very High. While these class names will be used throughout the text, STP did not originate at these levels. Phase I of this trial was specifically designed to develop these Interpretation Classes over four growing seasons.

Tillage operations and crop rotation were specific for each experimental site due to their geographic location and the cropping system typical in those locations. From 2011 through 2013 corn was grown in all sites except at Crookston were the crop rotation was corn, soybean, and hard red spring wheat in 2011, 2012, and 2013, respectively. All trial sites grew soybean in 2014. At crop maturity grain was harvested and grain yield determined. A grain sample from each designated split-plot was sent to Agvise for P concentration analysis.

Results

Common soil test procedures were conducted on soils from all sites to maintain common procedures even though different procedures are typically used for making P fertilizer recommendations among the sites. Crookston and Morris both have calcarous soils with higher pH (Table 2) and the Olsen STP procedure is used to make P fertilizer recommendations. All other sites use the Bray I procedure. Throughout the remainder of this report, STP and

Interpretation Class breaks will be determined using the Olsen procedure for the Crookston and Morris sites and the Bray I procedure reported for all other sites.

The Interpretation Class breakdown used in Minnesota with either the Bray I or the Olsen P STP procedures are illustrated in Table 1. At the initiation of this experiment all the sites generally had STP levels in the upper Low to upper Medium range (Table 1 and Table 2). Developing a separation in Interpretation Classes within each experimental site was planned as an accumulative process over the next four growing seasons. For producers wishing to build STP to the High Interpretation Class it is recommended they do so over four to eight growing seasons to spread the cost of the strategy over a longer period of time. In this experiment, we selected a four growing season period that should immulate an aggressive producer practice (Phase I).

The development of Interpretation Classes over time within each experimental site is illustrated in Fig 2. There was a depletion of soil P, as suggested by STP levels, in treatments that did not receive any P fertilizer (Low) during the Phase I period, yet this plots continued to be quite productive (Fig 3). Phosphorus fertilizer was applied to all other plots at increasing rates to either maintain the Medium level or build to a High or Very High level during Phase I. STP levels tended to increase throughout the Phase I period as P fertilizer applications increased annually and accumulatively. At Becker, Lamberton, and Waseca, building STP to the desired levels occurred quite rapidly and by the second year of the experiment may have been at targeted Interpretation Classes. At Crookston and Rochester an additional year was required to achieve the desired Intrepretation Class. The 2014 growing season actually became a maintenance year for STP levels and a preparation year for Phase II of the exeperiment that will be described below.

Throughout the Phase I period, grain yield was monitored from each treatment. This data is illustrated in Fig 3 along with statistical results from individual site-years. Crookston and Morris tended to have lower yields than the other four sites. Note: Crookston grew corn in 2011. At Lamberton and Waseca, yields in 2012 and 2013 were less than 2011 due to dry conditions. The Low treatment tended to have lower grain yields than any of the other treatments at Becker, Waseca, and Morris. However, there was only a difference between Medium and High classes at Becker (not all years), Waseca, and Morris. Not always were any of these differences significant. There was no yield difference among Intepretation Classes at Rochester or Lamberton in any year or at Crookston in 2012 and 2013 when soybean and spring wheat were planted. At the time of this writing, yields from 2014 had not yet been compiled.

To this point we have ben successful in developing a range in STP levels and Interpretation Classes at each of the six experimental sites. The soils at all sites were responsive to varying application rates of P fertilizer, though some were more responsive than others. During the Phase I period, grain yield response to the treatments was quite variable among sites especially when considering the yield response to increasing STP from the Medium to the High Interpretation Class.

Phase II of this experiment begins in the fall 2014 with the implementation of treatments to specific split-plots. The four split-plots in each whole plot will be paired. One randomly selected pair will be fertilized to maintain the current STP level. The second pair of split-plots will be used for experimentation in 2015. One split-plot will receive no P fertilizer, that crop will utilize residual soil P that has been built up during the Phase I period. The second split-plot will be fertilized at a rate to reduce to a low probability that P will be limiting. Treated split-plots in the Low, Medium, High, and Very High treatments will receive a broadcast rate of 150, 90, 30, and 30 lbs. P_2O_5 Ac^{-1}, respectively. In preparation for the 2016 growing season, the first split-plot pair will be similarly treated.

Table 1. Soil test phosphorus (P) Interpretation Classes and associated extracted P concentrations used in Minnesota.

	STP Interpretation Class				
Extractant	Very Low	Low	Medium	High	Very High
	--------------- ppm P extracted --------------				
Bray I-P	0-5	6-11	12-15	16-20	20+
Olsen-P	0-3	4-7	8-11	12-15	16+

Table 2. General soil characteristics at six experimental sites.

			CCE	O.M.	Initial Bray I	Initial Olsen
Site (Soil series)	Soil	pH	%	%	ppm P	ppm P
Becker: Hubbard ls	Sandy, mixed, frigid Entic Hapludoll	5.2	0.1		12.5	5.4
Crookston§: Gunclub sicl	Fine-silty, mixed, superactive, frigid Aeric Calciaquoll	8.1	2.5	4.8	11.4	9.5
Lamberton: Ves l	Fine-loamy, mixed, superactive, mesic Calcic Hapludoll	5.4	0.2	3.4	10.8	6.3
Morris§: McIntosh sl	Fine-loamy, mixed, superactive, frigid Aquic Calciudoll	7.6	1.5		18.2	11.1
Rochester*: Mt. Carrol sil	Fine-silty, mixed, superactive, mesic Mollic Haludalf	7.5	0.5	4.3	13.7	8.6
Waseca: Nicollet cl	Fine-loamy, mixed, superactive , mesic Aquic Hapludoll	6.0	0.1	4.7	14.2	6.6

*Site was limed just prior to the initiation of the experiment

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

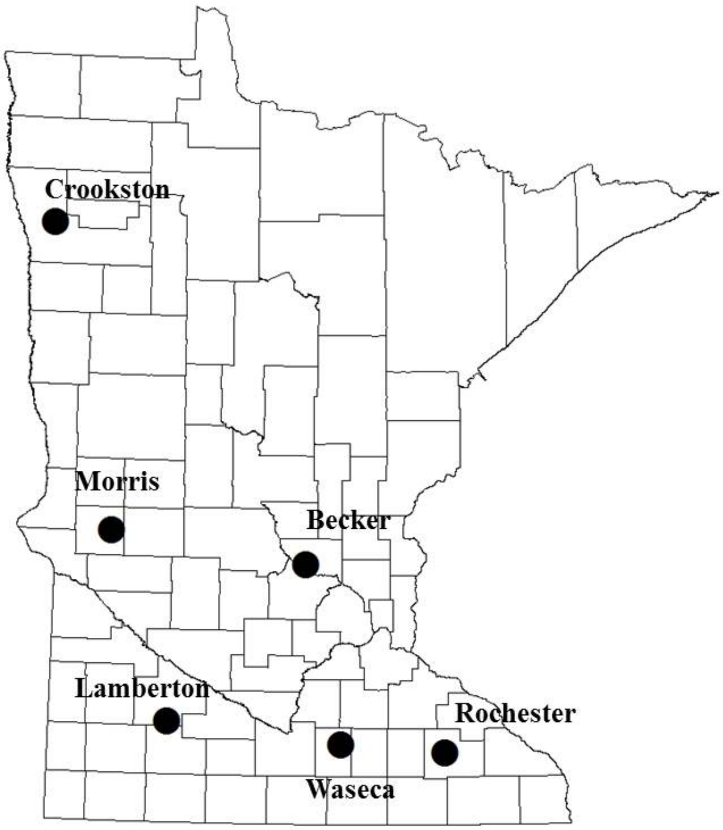

Figure 1. Geographic locations of six experimental sites.

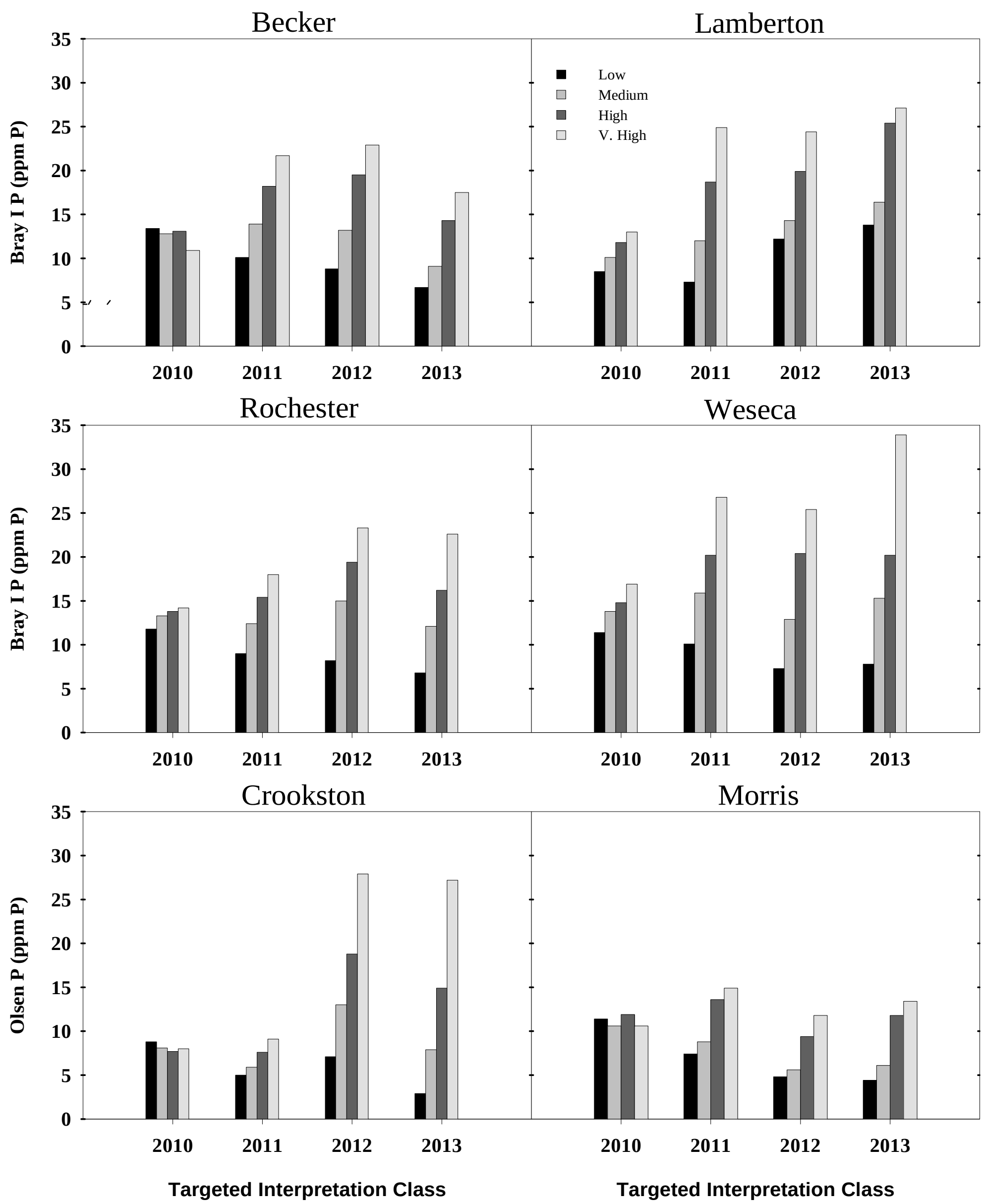

Figure 2. Soil test phosphorous (STP) levels within each targeted STP Interpretation Class at six locations over 3 to 4 years of the Build Period phase of the experiment. Note: STP at Crookston and Morris are Olsen P levels and the others are Bray I P.

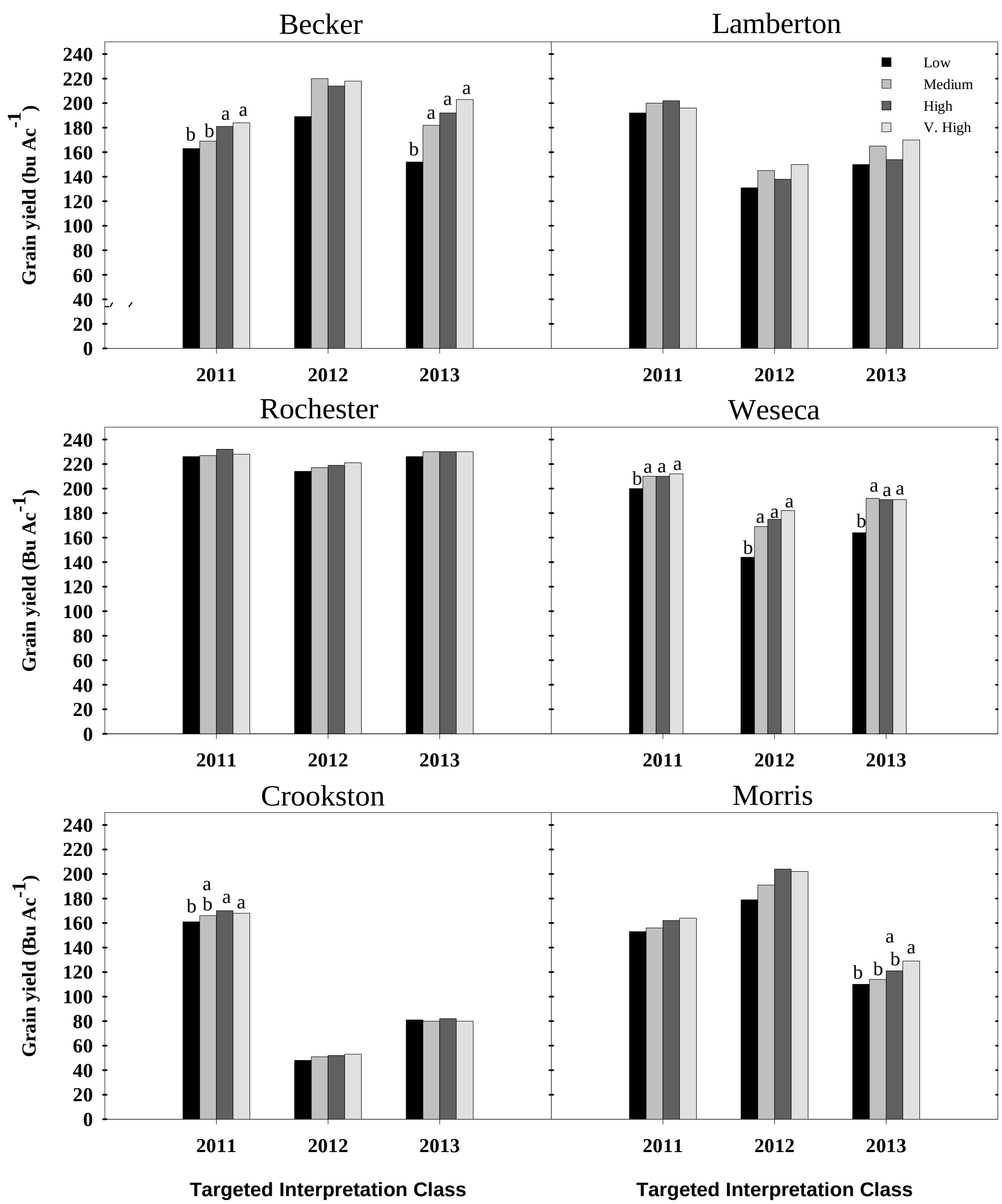

Figure 3. Grain yield of each targeted STP Interpretation Class treatment over 3 growing seasons at six locations. Note: All sites grew corn in all years except Crookston where the crop rotation was corn (2011), soybean (2012), and hard red spring wheat (2013). Columns with similar letters were not significantly different when compared within individual locations and years. No letters above columns indicates there was no significant effects of any treatments.

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