SUSTAINABLE SUFFICIENCY: AN ALTERNATIVE PARADIGM FOR PHOSPHORUS FERTILIZER MANAGEMENT

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ABSTRACT

Sustainable, widespread adoption of conservation practices on-farm demands alignment of agronomic productivity and environmental protection goals. Phosphorus (P) fertilizer management is a critical control point for conservation P management, to reduce agricultural P loss to the environment. Phosphorus fertilizer recommendations follow either a low-P sufficiency (SF), or a higher-P build and maintain (BM) approach. Reduced P fertilizer inputs are recognized as an effective control measure to reduce P loss, but current low-P SF management is not the favored P rate decision making system for producers. Compared to BM, SF is viewed as unsustainable by producers as consecutive years of SF management will lead to a drawdown in soil test P (STP). To promote the adoption of conservation-minded P fertilizer management, and reduce P loss, a new paradigm for low input P management that aligns production and conservation goals is required.

To develop a sustainable sufficiency (SSF) P fertilizer management paradigm, we will establish an SSF maintenance threshold (SSF-MT). Soils with STP<SSF-MT are expected to respond to P fertilizer rates in excess of maintenance rates, with maintenance rates are determined based on expected P_2O_5 removal. Historical P response data is being analyzed to determine the MT and preliminary results will be presented. Additionally, novel field studies will validate the MT and investigate corn and soybean yield response to maintenance rates of P fertilizer across a range of STP. So far, preliminary 2023 results indicate a maintenance rate of P fertilizer is sufficient to meet crop P demand at STP as low as 10 ppm Mehlich-3. Eighteen additional field studies will be conducted in 2024.

INTRODUCTION

Phosphorus (P) fertilization is frequently required to maintain agronomic productivity; however, agricultural P is subject to runoff loss with substantial environmental consequences for surface water quality and safety. Aligning agricultural P demands with environmental protection from P loss is a critical step to improve sustainability of our production systems.

Current P fertilizer management decisions are made following a build and maintain (BM) or sufficiency (SF) program. A BM program aims to increase soil test P (STP) above the critical threshold for yield response, with P fertilizer inputs in excess of expected crop P removal. The increased STP is then maintained above the critical threshold with routine maintenance applications of P fertilizer, even to soils where we would not expect crop response to P fertilizer. Under SF management P fertilizer decisions are made based on current STP and expected yield, with rates based on capturing 95% of maximum yield. Under SF management, P fertilizer is only recommended when STP is less than the critical threshold for yield response. The current critical threshold for yield response in Kansas is 20 ppm Mehlich-3 P. From a producer perspective, SF is often viewed as unsustainable as SF management year over year will draw STP down into the low or very low fertility range. Environmentally, SF management is superior to BM as it is a lower P system with less P susceptible to environmental loss. Optimizing P fertility management to ensure producer needs are met with environmental protection goals is critical, and neither SF nor BM management offers this combined outcome.

Agronomic and economic evidence in support of a BM program is limited; long-term data from Nebraska indicated BM did not benefit corn yield compared to SF management over a 12-year period (Olson et al., 1987). The cost of BM management was almost double the cost of SF, and BM increased STP almost threefold. A more recent study from Minnesota showed similar results, with no corn yield increase in response to BM management compared to SF (Fabrizzi et al., 2017). Similarly, a comparison of corn yield in response to build rates of P fertilizer and crop removal rates found no difference in corn production between the ‘high P’ and ‘low P’ intensity systems (Wortmann et al., 2018). Evidently, increased STP from BM systems does not consistently equate to increased crop production. Increased STP comes at a greater environmental risk, with higher concentrations of STP subject to increased P loss in runoff water (Osmond et al., 2019; Sharpley, 1995).

The substantial economic investment and environmental risk associated with a BM program may not be necessary to maximize agronomic productivity. At the same time, traditional SF is interpreted by producers as posing a higher risk to production due to the uncontrolled drawdown of STP overtime and variability of crop response to P across STP concentrations. An alternative strategy that better accommodates producer preferences and the environmental need to reduce STP is thereby necessary to advance sustainability of P fertility management. We will define a sustainable sufficiency (SSF) paradigm that combines reduced inputs and lower STP of a traditional SF system with benefits of risk management from a BM system. Our specific objectives are to: i) investigate corn and soybean yield response to a maintenance rate of P fertilizer across a range of STP concentrations, using novel field studies and ii) determine the SSF maintenance threshold (SSF-MT) STP using historical data.

MATERIALS AND METHODS

Field Study

Maintenance rate studies will be conducted directly overtop of traditional P rate response studies from the previous growing season to capture crop response to maintenance rates across a range of background STP concentrations. In 2023, four maintenance sites were established in Riley, Reno, Republic, and Franklin counties. The Republic location was established on a soybean P rate response study from 2022 that included rates of 0, 40, 80, and 120 lbs P_2O_5 ac^{-1} as MAP. The other three locations were conducted on top of 2022 corn sites that had received P rate treatments of 0, 30, 60, 90, and 120 lbs P_2O_5 ac^{-1}. These sites were planted to soybean in 2023. Maintenance rates and target yields for each site are in Table 1.

Table 1. Maintenance rates, associated target yields, and STP (Mehlich-3) range for each 2023 maintenance site.

Location	Target Yield (Crop)	Maintenance Rate Applied	STP Range
Riley	60 bu ac^{-1} (soybean)	48 lbs P_2O_5 ac^{-1}	6-43 ppm
Reno	65 bu ac^{-1} (soybean)	52 lbs P_2O_5 ac^{-1}	17-40 ppm
Republic	250 bu ac^{-1} (corn)	82 lbs P_2O_5 ac^{-1}	5-21 ppm
Franklin	50 bu ac^{-1} (soybean)	40 lbs P_2O_5 ac^{-1}	4-31 ppm

Maintenance rates were determined based on target yield and expected removal, using standard average removal values of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Maintenance treatments were broadcast by hand, as MAP, to each plot immediately following planting in the spring. Yield data was collected by harvesting the center two rows of each plot and correcting grain moisture to 13%. Harvest data was analyzed by ANOVA using PROC GLIMMIX in SAS. There will be an additional 18 maintenance sites in 2024.

Historical Data Analysis

Data from P rate response studies conducted in KS from 1980 to present were compiled, including STP and yield data. Our preliminary dataset includes 20 corn and 9 soybean P response trials. Yield response to P fertilizer rate was determined from published results or using ANOVA for studies with raw data available. A linear-plateau model was fit to data from each responsive site, using PROC NLMIXED in SAS, to determine optimum P fertilizer rate (P_O). For sites with no yield response to P fertilizer, P_O was set to zero. Phosphorus removal (P_R) at P_O was calculated based on standard estimates of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Using P_O and P_R, delta P_2O_5 (ΔP_2O_5) was calculated for each site-year, using the following equation:

$$\Delta P_2O_5 = P_O - P_R$$

The ΔP_2O_5 values were plotted against background STP for each site-year. Once the dataset is complete, a model will be fit to the ΔP_2O_5 data to determine the relationship between ΔP_2O_5 and STP; theoretically, the optimum STP for maintenance, our SSF-MT, would be the STP at which $\Delta P_2O_5 = 0$, as this is where $P_O = P_R$.

RESULTS AND DISCUSSION

Field Study

Preliminary results from 2023 indicate a maintenance rate of P fertilizer was enough to meet crop demand, even with STP <5 ppm. None of the sites had a significant yield response to increased STP with a maintenance rate of P fertilizer applied (Figure 1).

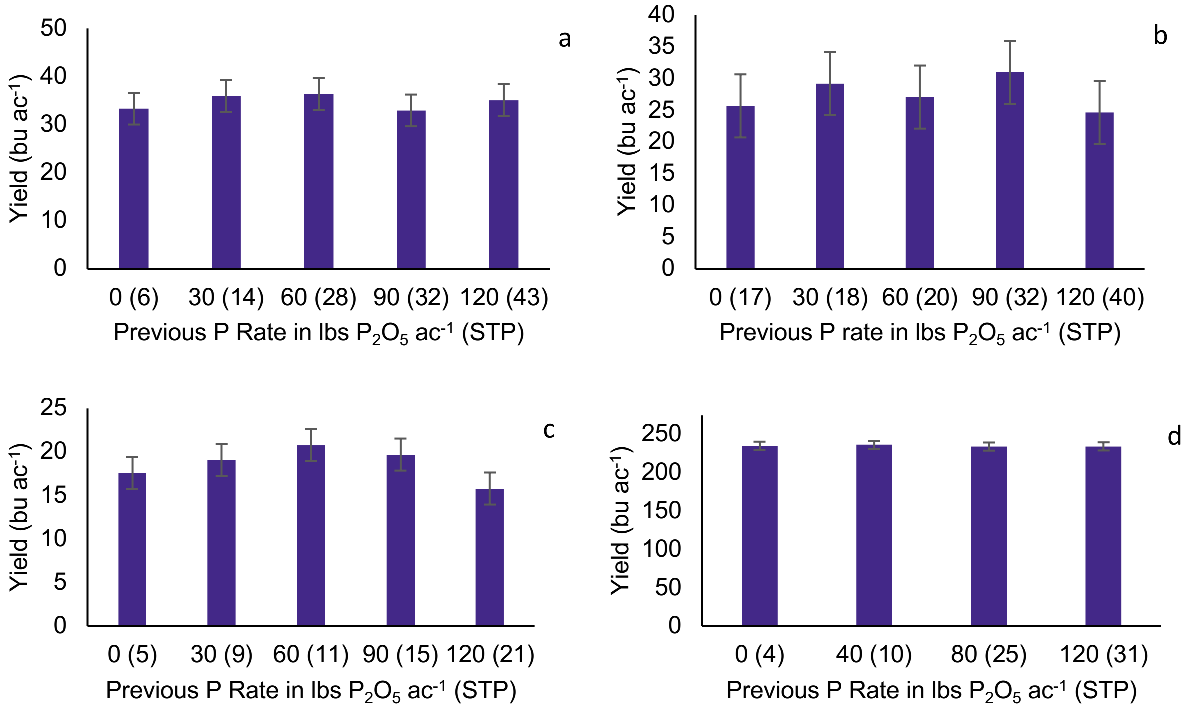

Figure 1. Soybean yield from Reno Co. (a), Riley Co. (b), Franklin Co. (c) and corn yield from Republic Co. (d) with a maintenance rate of P fertilizer applied as a spring broadcast application of MAP (n.s.)

The three soybean site-years underperformed achieving only 36 to 54% of target yield, likely due to dry growing season conditions. As maintenance rates applied were based on expected yield and removal, our applied P rates were greater than actual crop removal. In a year where actual and target yields are closer, STP could play a larger role in yield response to maintenance rates of P fertilizer. That being said, the corn site-year achieved an average of 94% of target yield and there was no difference in yield between a background STP of 4 ppm and 31 ppm with a maintenance rate of P fertilizer applied.

Historical Data Analysis

Out of 20 corn site-years, only five required P fertilizer to optimize yield and only one of these site-years required more than a maintenance rate of P fertilizer to reach optimum yield (Figure 2). The dataset includes a number of sites with $P_O < P_R$, more than we anticipated, particularly for sites with background STP less than 20 ppm, the current critical threshold for yield response to P fertilizer. Given this, and the large spread in the data, we have not yet attempted to fit a linear model to determine the optimum SSF-MT. Model fitting will occur as more data points are added, particularly as we add additional site-years in the low to very low STP range.

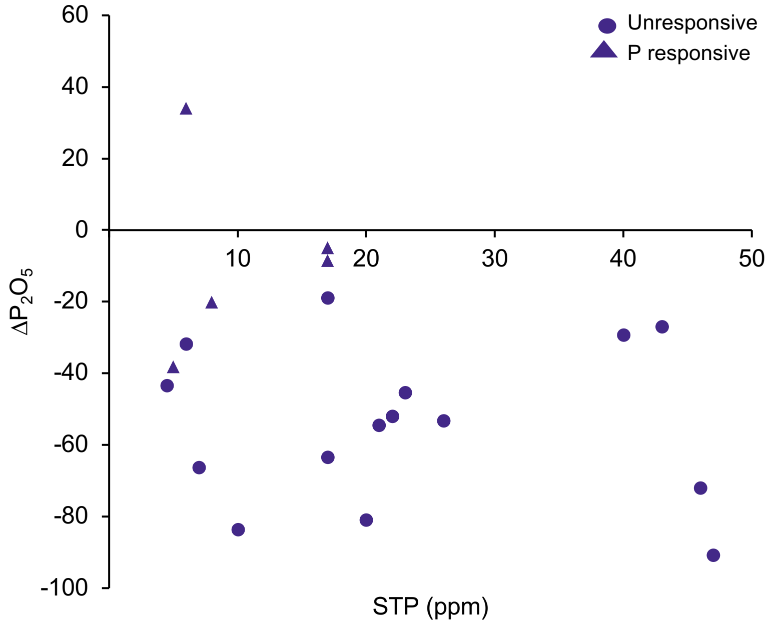

Figure 2. Preliminary ΔP_2O_5 results for corn (n = 20), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

None of the nine soybean site-years included in our initial analysis required P fertilizer to optimize yield (Figure 3). As such, a maintenance rate of P fertilizer was enough to optimize yield for all of these sites. Similar to the preliminary corn dataset, there were also more soybean site-years with $P_O < P_R$ than anticipated. Model fitting to determine the theoretical optimum STP for maintenance will be carried out once the dataset is complete.

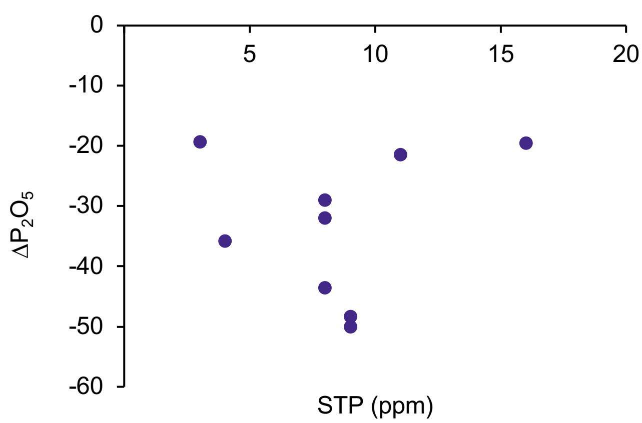

Figure 3. Preliminary ΔP_2O_5 results for soybean (n = 9), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

Initial results from the historical data analysis indicate a maintenance rate of P fertilizer may be more than enough to optimize yield >95% of the time. Therefore, we may be able to set a MT for SSF management that is below 20 ppm Mehlich-3, without consequences to crop yield. Model fitting from historical data analysis and results from the 2024 field studies will be used to suggest a MT to determine STP where maintenance rates are sufficient to achieve yield potential.

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