DEVELOPING A SUSTAINABLE SUFFICIENCY PARADIGM

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ABSTRACT

Agronomic productivity and environmental protection goals of conservation practices must align for sustainable, widespread adoption on-farm. Phosphorus (P) fertilizer management is a critical control point for reducing consequences of P loss from agricultural fields to the environment. Reduced P fertilizer inputs are recognized as an effective and necessary control measure to limit P loss; however, current P fertilizer recommendation systems do not support this agronomically. Phosphorus fertilizer recommendations follow either a sufficiency (SF) or a build and maintain (BM) approach. Although SF is a low input recommendation system, it is viewed as unsustainable by producers as consecutive years of SF management will lead to a drawdown in soil test P (STP). To promote adoption 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 the sustainable sufficiency (SSF) P fertilizer management paradigm, historical P response data will be analyzed with a new approach to determining critical soil test P threshold for maintenance. Additionally, novel field studies will validate the theoretical optimum STP threshold for maintenance P fertilization developed from historical data, and investigate the effect of STP on yield response of corn and soybean to maintenance rates of P fertilizer. Preliminary findings from historical data analysis and the 2023 growing season will be presented.

INTRODUCTION

A hallmark challenge of P management is balancing crop response to P fertility and P fertilizer, while limiting P loss from agricultural fields to the environment. Phosphorus fertilizer management typically follows one of two contrasting philosophies: build and maintain (BM) or sufficiency (SF). A build and maintain approach typically increases soil test P (STP) above the critical threshold for yield response, and maintains it there, with regular P fertilizer applications. Sufficiency relies on annual P fertilizer applications based on the likelihood of crop response in that year. Unlike BM which generally raises STP and sustains higher levels in the system, SF can draw down STP overtime, as SF P fertilizer rates are often not enough to replace crop P removal. Optimizing P fertility plans with an alternate management strategy to better balance crop response to P fertility and P fertilizer in the year of application, while maintaining lower STP in the system, could reduce the environmental threat of P loss from agricultural fields, and optimize farm economics.

Historically, long-term research in Nebraska showed no benefit of a BM strategy, compared to SF, over 11 or 12 years for corn yield (Olson et al., 1987). In that study, the cost of build and maintain fertilization was almost double the cost of sufficiency management. Additionally, under a BM plan, STP increased to almost three times the STP of the sufficiency treatment. More recently, data from Minnesota showed no corn yield benefit to a BM approach, compared to a SF strategy, where P fertilizer rate decisions were made based on soil test P and the critical threshold for crop response (Fabrizzi et al., 2017). Similarly, Wortmann et al. (2018) found build rates of P fertilizer did not increase corn yield, compared to plots with P fertilization according to crop removal rates. From these studies, we see that an increase in STP as a result of BM management does not consistently translate to an increase in crop yield.

Along with agronomic and economic considerations there are potential environmental consequences of a BM strategy. Build and maintain systems, with higher P inputs, will lead to higher STP compared to a SF approach (Pierzynski & Logan, 1982). Higher STP concentrations are related to increased risk of P loss from the system (Osmond et al., 2019; Sharpley, 1995). Because of its role in P loss, managing P inputs and fertility to sustain lower concentrations of STP can be an important control measure to reduce P loss (Osmond et al., 2019). A BM system does typically represent a larger risk to the environment, and the work of Olson et al. (1987), Fabrizzi et al. (2017), and Wortmann et al. (2018) indicates a lack of consistent productivity benefits to offset the increased environmental risk.

A BM strategy may not be necessary to maximize yields, and can present a substantial economic investment, and environmental risk. However, the lower input SF approach may pose too great of a production risk to farmers, perceived or real, given the variability in P response even at high STP levels. Evidently, an alternate strategy to better balance crop response to P fertility and P fertilizer could be useful to reduce STP values maintained in fields, reduce P fertilizer inputs, and provide better mitigation of yield loss risk compared to a traditional SF strategy. As such, we will define a sustainable sufficiency (SSF) strategy to bring together the benefits of lower inputs and lower STP maintained in a traditional SF system, with the risk mitigation of maintaining a target STP level of a traditional BM strategy. Our 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 theoretical optimum STP for maintenance P fertilizer management, using historical data.

MATERIALS AND METHODS

Field Study

To investigate the effect of maintenance P fertilizer applications across a range of STP concentrations, our sites require a gradient of STP across plots. To achieve this, maintenance rate studies will be directly imposed over P fertilizer rate studies conducted in the previous growing season. In 2023, four site trial locations were selected in Riley, Reno, Franklin, and Republic counties in KS. The Riley and Reno sites are included in these results. Both of these locations had hosted a traditional P rate response study in 2022, with P rate treatments of 0, 30, 60, 90, and 120 lbs P_2O_5 ac^{-1} applied to four replicates. Post-harvest soil samples were collected from each plot following the 2022 season. The Riley and Reno sites were planted to soybean in 2023 and received a maintenance rate of 48 and 52 lbs P_2O_5 ac^{-1}, respectively, based on yield goals of 60 and 65 bu ac^{-1}. Maintenance rates were determined using expected removals for each yield goal, using standard removal estimates of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Maintenance rates were applied to each plot immediately following planting in the spring, using MAP. 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

Soil test and yield data from traditional P rate response studies from KS, from 1980 to present, were compiled. The preliminary dataset includes 20 corn and 9 soybean response trials. Crop yield response to P fertilizer was ascertained from published results, or determined using ANOVA for studies with available raw data. PROC NLMIXED in SAS was used to fit a linear-plateau model to determine optimum P fertilizer rate (P_O) for each site with yield response to P fertilizer; P_O was set to zero for unresponsive site-years. Once P_O was established for each site-year, P removal by the crop at P_O (P_R) was determined based on yield at P_O and standard P removals of 0.33 lbs P_2O_5 bu^{-1} for corn and 0.8 lbs P_2O_5 bu^{-1} for soybean. Delta P_2O_5 (ΔP_2O_5) was then calculated for each site-year, using the following equation:

$$\Delta P_2O_5 = P_O - P_R$$

Calculated ΔP_2O_5 values were plotted against 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 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 two of the soybean maintenance studies from 2023 indicate a maintenance rate of P fertilizer was enough to meet crop demand, even when STP was <10 ppm. Neither site had a significant yield response to increased STP with a maintenance application of P fertilizer (Figure 1). Therefore, STP >20 ppm, the current critical threshold for yield response in KS, was not required to achieve yield with a maintenance rate of P fertilizer applied.

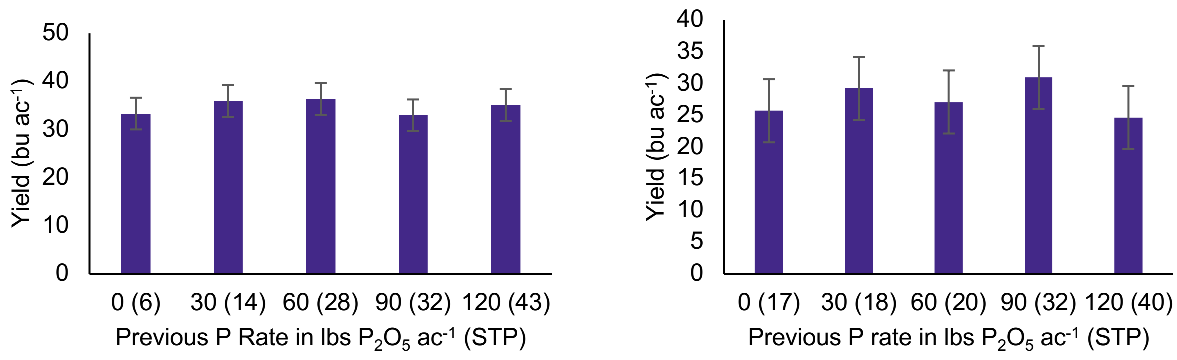

Figure 1. Soybean yield from Reno Co. (L) and Riley Co. (R) with a maintenance rate of P fertilizer applied as a spring broadcast application of MAP (n.s.)

Historical Data Analysis

For corn, only 5/20 site-years responded to P fertilizer and only one site-year required more P fertilizer than a maintenance rate to achieve optimum yield (Figure 2). At 19/20 site-years, a maintenance rate of P fertilizer would have sufficed to satisfy crop requirements for optimum yield. There were far more sites with $P_O < P_R$ than anticipated, particularly for site-years where STP was <20 ppm. Given the large spread in the data, and the number of site-years with STP >20 ppm, we have not yet attempted to fit a model to determine optimum STP for maintenance. Model fitting will take place once additional site-years in the low to very low STP range are added to the dataset.

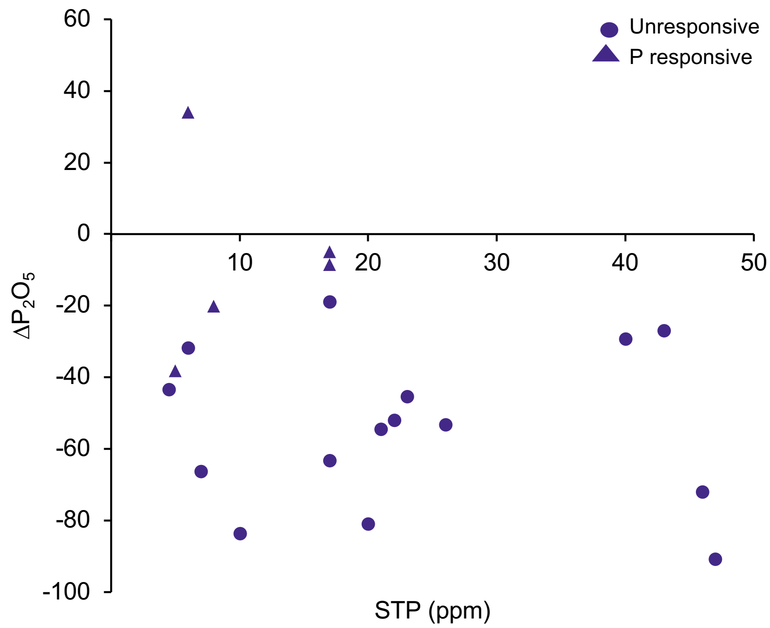

Figure 2. Preliminary ΔP_2O_5 results for corn (n = 20), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

For soybean, none of the nine site-years included in the preliminary analysis responded to P fertilization (Figure 3). Thereby, at all of these site-years, a maintenance rate of P fertilizer would have been enough to meet P demands at optimum yield. Similar to the corn site-years, there were more site-years with $P_O < P_R$ than anticipated. Model fitting to determine theoretical optimum STP for maintenance will take place in 2024, once the dataset is complete.

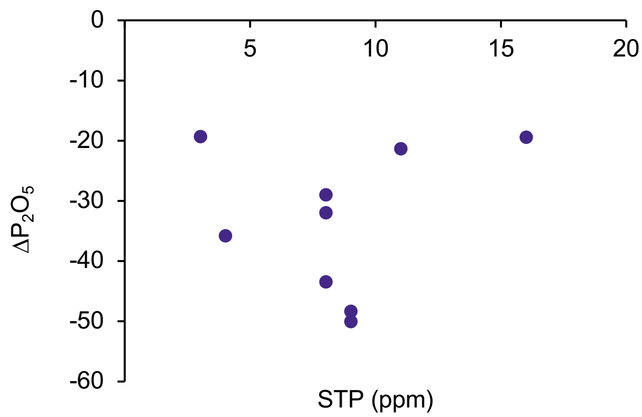

Figure 3. Preliminary ΔP_2O_5 results for soybean (n = 9), where ΔP_2O_5 is the difference between optimum P fertilizer rate, P_O, and P removal at optimum yield, P_R.

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