CAN SOIL HEALTH METRICS IMPROVE SOIL FERTILITY RECOMMENDATIONS IN MISSOURI CORN PRODUCTION?

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ABSTRACT

It is speculated that integrating soil health (SH) with soil fertility (SF) testing would improve fertilizer recommendations. However, impacts of SH properties, specifically soil biological properties, on fertilizer demand are not quantified. The objective of this research was to explore corn (Zea mays L.) yield response to phosphorus (P) and potassium (K) fertilization as influenced by established SF analysis and common SH metrics. From 2018 to 2020, 532 fertilizer response plots (1592 ft2) were implemented in 84 producer fields across central Missouri. Response plot treatments were 1) an unfertilized control, 2) 100 lbs ac-1 of K2O, and 3) 100 lbs ac-1 of P2O5. Each treatment received the same producer-specific nitrogen (N) rates, with an additional 40 lbs N acre-1 applied near V6 corn growth stage to prevent N deficiencies. Random forest analysis was used to model yield response to P and K fertilization and to investigate the influence of SH and SF analysis on model performance. Two-thirds of established monitoring sites were below established P and K soil-test critical concentrations—with 32% and 36% of the low fertility plots responding to P and K fertilizer application, respectively. The most consistent P and K yield improvements occurred in established “Very Low” and “Low” fertility ratings with yield improvement at 52% and 56% of the sites respectively. However, integrating SH and SF for predicting yield response was only minimally helpful, resulting in R2 values of 15% and 7% for the P and K treatments, respectively. The low R2 values are likely due to the variability in P and K availability and crop demand introduced by the diversity of cropping systems, management practices, and soils of the research sites. Assessment of variable importance in the models indicated that the established University of Missouri recommended SF tests best predicted grain yield responsiveness to P and K fertilization. The addition of SH metrics provided minimal additional predictive power. Although improved SH may offer multiple environmental or agronomic benefits, this study indicates that across central and northern Missouri soils, established physiochemical SF analysis remains the most effective tool to guide P and K fertilizer decisions in corn production.

INTRODUCTION

Modern-day fertilization contributions 40-60% of current corn grain yield in the United States but offsite transport of fertilizer nutrients leads to regional, local, and worldwide environmental issues (Stewart et al., 2005). The bedrock of fertilizer recommendations is soil fertility (SF) testing. Soil fertility testing uses established correlation datasets between soil nutrient concentrations and relative yield response to identify whether estimated soil nutrient supply suffices for crop demand (McGrath et al., 2014). For crop phosphorus (P) and potassium (K) nutrient needs, these relationships also identify nutrient concentration thresholds where additional fertilizer will not improve yield (Fryer et al., 2019). This, in-turn, serves to recommend where not to fertilize, and prevents potential nutrient runoff from cropped fields (McGrath et al., 2014). However, recent research has highlighted possible improvements in fertilizer recommendations associated with soil-test P (STP) and soil-test K (STK), with reported accuracies as low as 40% (Fryer et al., 2019). Investigating inadequacies and improving these recommendations are crucial in maintaining profitability and averting ongoing environmental pollution.

The University of Missouri P and K recommendations rely upon physiochemical soil extractions and yield response relationships developed decades ago (Bray, 1945). These relationships were developed in cropping systems with regular and deep tillage, limited crop rotations, and fallow periods. In contrast, modern conservation practices include diversification of crop rotations, incorporating cover crops, and minimizing tillage. These conservation practices improve physical, chemical, and biological soil properties, creating an environment different from when SF recommendations were developed. Despite these changes in common management practices, SF analysis and evaluations have largely remained unchanged. Monitoring these improvements led to the development of 'soil health' (SH) and the focus on improved soil biological properties. However, it remains uncertain whether enhancements in nutrient cycling and availability from improved soil biological properties affect SF recommendations. Current SF assessments of nutrient status are physiochemical and do not measure soil biological properties and do not directly measure the impact from soil improvements through conservation systems on labile soil nutrients. Because of this void, some have recommended expanding SF assessments to include soil biological assessments. However, these asserted benefits remain conceptual, with little empirical evidence (Bünemann et al., 2018).

Integrating soil biological tests into SF tests offers a unique opportunity to refine fertilizer recommendations to reflect modern cropping systems and recent improvements to assess soil biology. The development of economical soil biological tests in the modern era provides opportunities to explore how characterizing the living part of the soil could improve fertilizer recommendations (Wade et al., 2020). The research objectives include evaluating current University of Missouri P and K fertilization recommendations and evaluating corn yield response to P and K fertilization as impacted by SF and SH metrics.

MATERIALS AND METHODS

Research was implemented in mid-Missouri across 84 commercial fields in diverse management practices over three seasons (2018-2020). To evaluate response to P and K fertilization across these diverse environmental conditions, multiple fertilizer response trials (i.e., 'monitoring sites') were established on these fields. Each monitoring site was a 1593 ft^2 and included four 398 ft^2 non-replicated single-rate fertilizer treatments with a total of 446 total monitoring sites. Monitoring sites followed a standardized plot plan with the following treatments: 1) unfertilized control, 2) 100 lbs $acre^{-1}$ of K_2O using KCl (0-0-60), and 3) 100 lbs $acre^{-1}$ of P_2O_5 using triple superphosphate (0-46-0). Fertilizer treatments were applied before or at planting while cooperating farmers selected hybrids, weed control, tillage, N fertilization, planting dates and other practices based on their standard management practices. An additional 40 lbs N acre^{-1} were applied near V6 corn growth stage to prevent N deficiencies. Planting dates varied by climate and soil properties and ranged between April 5 toJune 10.

Prior to fertilization (March-April), SH and SF samples were collected for each monitoring site. Soil samples were collected from eight randomly sampled 0-15 cm depth cores. Soil fertility samples were air-dried and submitted for analysis to Ward Laboratories (Ward Laboratories, Kearney, NE). Soil fertility analysis included organic matter (OM), Bray-1 P, ammonium acetate K extraction, sulfate sulfur, cation exchange capacity (CEC), pH, and particle size. Soil biological tests for SH metrics were completed in the USDA-ARS Soil Quality Lab on the University of Missouri Columbia Campus and included: soil organic carbon (SOC), total nitrogen, permanganate oxidizable carbon (POXC), 4-day soil respiration, autoclaved citrate extractable protein (ACE Protein), acid phosphatase activity, aryl-sulfatase activity, and β-glucosidase activity. Soil health samples were broken into two horizons 0 to 5 and 5 to 15 cm, stored in a cooler at 1.6° C, and later processed by passing through a 1 cm screen, air-drying, and dry sieving through a 2 mm screen. For POXC and SOC, soils were ground to a powder prior to analysis. Grain yield was hand harvested at maturity and weights were adjusted to 15.5% moisture from 118 ft^2 from each treatment. Yield response was calculated as the control treatment divided by the respective fertilizer treatment (P and K) at that monitoring site. Statistical approaches used relative yield as the response variable, with the suite of SF and SH metrics as explanatory variables. Relative yield was fit with quadratic plateau models to evaluate current SF recommendations with soil test K and soil test P. Random forest algorithms with variable importance plots were used to evaluate whether integrating SF and soil biological tests improve predictions of relative yield.

RESULTS AND DISCUSSION

University of Missouri Soil Fertility Recommendations

At monitoring sites below the recommended soil test P and K levels, there was an average 10% yield increase for P fertilization and 11% yield increase for K fertilization. Fertilizer application of P and K improved yield at 46 and 36% of total monitoring sites respectively. The greatest rate of responses to fertilization occurred in the “Low” and “Very Low” fertility ratings with yield response at 52 and 32% of monitoring sites for P fertilization respectively (Figure 1). Despite being below recommended STP critical concentration, monitoring sites with “Medium” STP responded with similar rates as sites above the critical concentration (High, Very High, and Extremely High). Similar trends were observed in the K treatments, with the greatest rate of response to K fertilization occurring in the “Low” fertility rating (Figure 1). The “Medium” and “High” fertility ratings contained similar response to fertilization. The response rate in the “High” fertility rating was greater than expected considering the soil test K concentration was above recommended concentrations.

Variability in fertilization above the critical concentration of STP and STK are well documented. Distributions of relative yield in the University of Missouri correlation datasets range 80-120% at high soil STP and STK values (Fisher, 1974). Stronger relationships than those observed in this dataset have been observed, but these strong relationships often include few sites typically under similar management practices.

Despite controlling these factors, significant variability can remain with critical soil test concentrations differing between 6-10 ppm between research sites (Dodd and Mallarino, 2005). These differences in P critical concentrations, in part, are due to better drainage properties which created a soil environment which promote root acquisition of available P from an overall improved growing environment (Dodd and Mallarino, 2005). The data reported in this dataset reflect over 20+ soil types with unique properties and management practices. Distinctive critical concentrations between soil types would introduce significant variability in yield response to fertilization near established critical levels and could explain the variability in yield response to fertilization for both P and K.

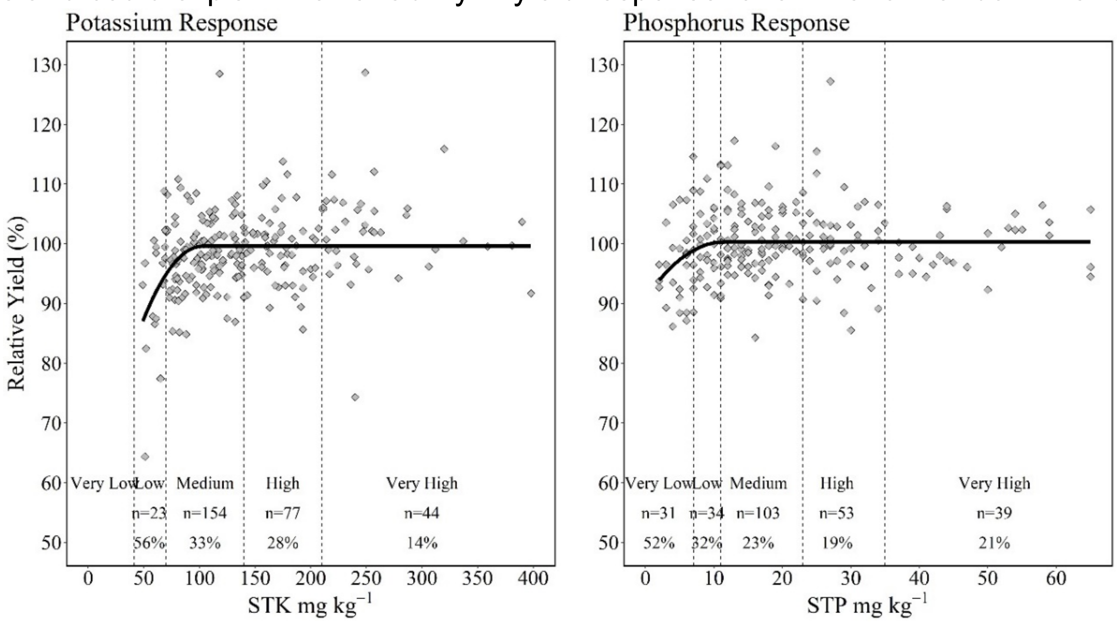

Figure 1: Relationships between soil test phosphorus (STP) and soil test potassium (STK) and relative yield of corn across all experimental years and overlaid with best-fit quadratic plateau linear functions. Vertical dashed lines represent University of Missouri SF ratings, which reflect the probability of yield improving from fertilizer application. Under each rating label is the number of observations and percent of observations with ≥ 5% yield increases shown.

Integrating Soil Health and Soil Fertility Metrics

The variability in yield response to P and K fertilization introduced significant challenges for model development and prediction. Traditional mixed linear approaches were unsatisfactory in capturing trends in this dataset; and machine learning approaches were required. The random forest model prediction of relative yield for P and K fertilization performed poorly, with a training dataset R^2 of 6 and15% respectively. Low R^2 values are common in regional assessment of relationships between soil test P and K with similar values observed in a regional assessment in the Northeast USA and Ohio (R^2 = 0.11—0.28) (Heckman et al., 2006). Poor model performance is likely due to the variability in P and K crop demand introduced by the diversity of cropping systems, management practices, and soils in which the plots were deployed.

Relative yield response to P or K fertilization was the explanatory variable used to evaluate the integration of SH into established SF analysis. Integration of SH metrics marginally improved model performance relative to current SF soil tests (Table 1). The addition of SH metrics marginally improved the out-of-bag error R^2 values for the calibration dataset for both P and K fertilization (Table 3). However, no substantial improvement in RMSE from the calibration to the validation datasets indicates the supplementary factors did not improve model accuracy. These results differ from conclusions observed with N fertilization in which soil biological tests have improved traditional SF metrics (McDaniel et al., 2020). These differences likely evolve from differences in P and K crop demand, crop sensitivity to fertilization, and differences in nutrient cycling. Biological processes govern the cycling and availability of N, while chemical and physical processes drive P and K availability to crops. The SH metrics included in this study were biological analyses and reflect nutrient cycles that are microbiologically driven. Chemical and physical processes dominate P and K nutrient transformations and availability; therefore, introducing biological analysis may not directly translate to improvements in evaluating P and K crop availability.

Table 1. Model statistics for random forest algorithms with relative yield response to phosphorus or potassium fertilization as dependent variables. Included explanatory variables were suites of soil fertility, soil health, management, and environmental variables. That dataset was partition into 80 % (n=183) for model calibration with the remaining 20% (n=45) used for validating developed model with each random forest model trained on 501 trees. RMSE was calculated from the difference between predicted relative error and observed relative error.

Model Inputs and Dependent Variable		**Calibration**		**Validation**
	mtry	R^2	***RMSE***	***RMSE***
Relative Yield to Potassium Fertilization				
Soil Fertility	1	86%	7%	6.7%
Soil Fertility + Soil Health Metrics (Integrated)	2	92%	7%	6.4%
Relative Yield to Phosphorus Fertilization				
Soil Fertility	1	89%	6%	6.5%
Soil Fertility + Soil Health Metrics (Integrated)	2	94%	6%	3.0%

Variable importance analysis of relative yield response to P and K fertilization was used to evaluate the importance of each explanatory variable (Figure 2). Bray-1 and CEC were identified as the top indicators of yield response to P fertilization for both the SF and integrated random forest models. The Bray-1 soil extraction is currently the only soil metric used for the University of Missouri P recommendations. These data suggest CEC could reflect factors that govern yield response to P fertilization that are not currently realized in the Bray-1 test. Similar observations were made in Iowa where differences in yield response to P fertilization between field sites were attributed to drainage properties and an overall soil environment, in addition to the Bray-1 soil test (Dodd and Mallarino,, 2005). Cation exchange capacity is related to several soil properties, including soil texture and soil OM. However, percent clay was also included in the SF model and considered relatively unimportant. Therefore, CEC likely reflects additional soil properties beyond soil texture, such as OM, to explain its relatively high importance in predicting yield response to P fertilization. For both the SF and integrated random forest models, the ammonium acetate K extraction was considered the most important variable in predicting yield response to K fertilization, with CEC also considered an important factor. This follows the current University of Missouri recommendation system that integrates these two variables. The inclusion of soil test K as the top variable for both variable importance methods confirms the relative power of this measurement in identifying soils responsive to K fertilization. However, further refinement of the current University of Missouri recommendations is required, when considering the relatively inconsistent response to P and K fertilization across central Missouri soils and cropping systems (Figure 1).

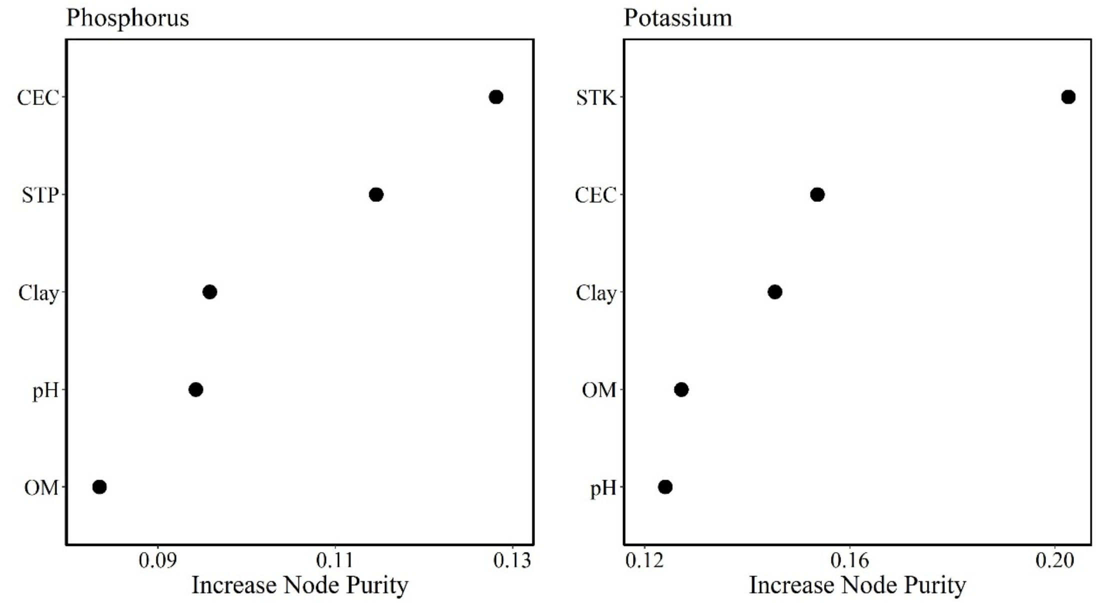

Figure 2: Variable importance plots for established random forest models that included soil fertility tests. Increase in node purity reflects a reduction in residual sum of squares at each split when summed over all splits and trees for each variable. The greater the number, the greater the relative importance in predicting yield response to P and K fertilization.

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