FIELD CORRELATION AND CALIBRATION OF SOIL-TEST PHOSPHORUS AND POTASSIUM FOR CORN AND SOYBEAN IN ILLINOIS

F. Bardeggia[1], B. Joern[2], T. Smith[3], and J.D. Jones[1]

[1]University of Illinois Urbana-Champaign, Department of Crop Sciences, Urbana, IL.
[2]Precision Planting, AGCO Corp., Tremont, IL. [3]Cropsmith, LLC, Farmer City, IL.

fbarde94@illinois.edu, (217) 249-6708

ABSTRACT

Effective phosphorus (P) and potassium (K) soil-test interpretation and fertilizer guidelines require each soil test to be field correlated with crop yield response to fertilization and calibrated to provide expected response probabilities. University of Illinois P and K guidelines require updates to reflect routinely used soil-test methods and current cropping systems. Field studies were established at eighteen sites across Illinois and Wisconsin to correlate soil-test P and K with corn and soybean response to fertilization and calibrate rate guidelines for both build and maintain and hybrid build and maintain systems. Soil P was measured using the Bray-1 (BP), Mehlich-3 colorimetric (M3P-COL), and Mehlich-3 ICP (M3P-ICP) tests. The ammonium acetate (AAK) and Mehlich-3 (M3K) tests were used to measure soil K. Soil-test P and K were analyzed as both oven-dried and field-moist using the Mehlich-3 test. Soil samples were collected from the 0 to 7-inch depth in the fall after crop harvest and spring prior to planting. Sites included sixteen soil series with silty clay loam to loamy fine sand textures, pH slightly acidic to slightly alkaline, and managed with either no-till or conventional tillage. Corn and soybean were grown each year at every site and were managed in corn-soybean rotations. Initial fall STP and STK ranged from 10 to 16 ppm M3P and 109 to 183 ppm M3K, respectively. Relationships between relative yield response and soil-test by each test and nutrient were described by fitting quadratic-plateau (QP), linear-plateau (LP), and exponential rise-to-maximum (EXP) models. Soil-test CC ranges for both corn and soybean were identified using all models that had significant fit to the data ($P \le 0.01$). Preliminary critical concentrations for M3P in the fall and spring were 13 ppm P and 20 ppm P, respectively. Critical STK concentrations for the M3K test were 146 ppm K when sampling in the fall and 226 ppm K with spring soil samples. Results are initial phases in providing updated soil-test interpretations and rate guidelines to inform P and K fertilization decisions in Illinois.

INTRODUCTION

Phosphorus (P) and potassium (K) fertilization guidelines that support profitable crop production and avoid nutrient losses require consistent and robust soil-test recommendations. Initial steps to refine Illinois P and K guidelines include field correlation of crop yield response to fertilization and soil-tests to identify critical soil-test concentrations (CC), and calibration to rate responses. Critical soil-test concentrations for P and K are generally defined as the soil-test values or ranges below, and above which crop responses to P and K fertilization are expected or not expected. Determining an appropriate critical soil-test concentration for a specific extractant, soil–plant category, and region is a fundamental step in using soil testing to develop reliable fertilizer recommendations (Mallarino & Blackmer, 1992). Current Illinois guidelines are solely based on Bray-1 and Mehlich-3 colorimetric determination methods for P, while K interpretation for ammonium acetate and Mehlich-3 tests are used. Field and laboratory research supporting current recommendations are greater than five decades old and require reexamination. This concern is amplified by the growing economic and environmental risks confronting farmers and crop advisors in the absence of contemporary calibration data.

Recent reach in the North Central region has indicated a need to revise state-specific guidelines. In Iowa, Mallarino (2023) has continuously updated the critical soil-test concentrations and fertilizer recommendations for P and K in Iowa. These updates are justified by substantial improvements in laboratory quality, the observed variability in yield response magnitudes, and an increased recognition of the inherent uncertainty in soil-test results. In Wisconsin, Jones et al. (2022) reported updated critical soil-test concentrations for P and K in corn and soybean, along with newly developed interpretations for extraction methods other than the Bray-1 test, which had not previously been available for these crops. Kaiser et al. (2023) also updated P and K fertilizer recommendations for Minnesota's major regional crops, employing Bray-1 and Olsen soil-test methods for P and ammonium acetate for K determination.

Therefore, the objectives of this study are to: (1) develop Illinois soil-test interpretations for P and K in soybean and corn using routine soil-test P and K methods to support the forthcoming revision of the Illinois Agronomy Handbook; (2) generate calibrated P and K fertilizer rate recommendations that integrate the 4R nutrient stewardship principles and key system practices ; and (3) establish preliminary criteria for assessing farm-specific economic and agronomic risks using ROI-based metrics.

MATERIALS AND METHODS

Site Descriptions and Management

Field experiments were conducted at sixteen locations in Illinois and two locations in southern Wisconsin across multiple years from 2022 to 2025. Multiple experimental sites were established at separate trials at each location, resulting in 110 site-years of P trials and 80 site-years of K trials (254 and 341 site x year x soil-test level combinations, respectively). Trials encompassed sixteen soil series with textures ranging from silt loam and silty clay loam to loamy fine sand, with all series included representing major soils in Illinois cropland. Soil organic matter ranged from 1.8 to 5%, and soil pH varied from acidic to slightly alkaline based on samples collected from the 6-inch depth. All trials followed a randomized complete block design with either (i) a full factorial arrangement of phosphorus (0 to 150 lb P_2O_5 ac^{-1}) and potassium (0 to 180 lb K_20 ac^{-1}) fertilizer rates or (ii) included all P and K rates independently, replicated four times. Phosphorus was applied in the fall after soil samples were collected as triple super phosphate (0-46-0) at all P rates and as ammonium polyphosphate (10-34-0) at rates of 25 and 50 lb P_2O_5 ac^{-1} in the spring at planting. Potassium was applied at potassium chloride (0-0-60) in the fall. All site-years were managed at corn-soybean rotations with each crop grown every year at most sites. All but 4 sites per year were managed with conventional tillage and the remainder were no-till.

Soil samples were collected in the fall and spring (6-inch depth) and analyzed for P using the Bray-1 (BP), Mehlich-3-colorimetric (M3P-COL), and Mehlich-3-ICP (M3P-ICP) methods. Soil samples were analyzed for K using the Mehlich-3 (M3K) and Ammonium Acetate extractions (AAK). Soil pH (1:1 ratio of soil or deionized water), Sikora buffer pH, and soil organic matter (loss on ignition) were also analyzed on most soil samples. All analysis methods followed the procedures suggested by the NCERA-13 north-central region soil testing committee (Frank et al., 1998) Laboratory analysis was conducted at the University of Wisconsin-Madison Soil and Forage Analysis Laboratory and select sampled analyzed at Radicle Lab® (Radicle Agronomics-Precision Planting, AGCO Corp.), using Microflow technology, which provides chemical soil-test data through a slurry method.

Statistics and Data Analysis

Differences among treatments corresponding to the different P_2O_5 and K_2O application rates were evaluated using analysis of variance (ANOVA) at a significance level of $p \leq 0.01$, and mean separation was performed using Fisher's Least Significant Difference (LSD) test. Relative grain yield (RY) was calculated for each trial by expressing the mean yield of the unfertilized treatment (averaged across replications) as a percentage of the mean yield of the treatments that produced the statistically maximum yield. This approach to determining relative yield is referred to as the "StatMAX" method (Pearce et al., 2022).

Regression analyses were conducted to compare the amounts of P and K extracted by each soil test across all trials. Relationships between relative yield response and soil-test values for each method were evaluated using the subset of response trials. For each P and K extraction method, relationships between relative yield and soil-test concentration were examined, and ranges of critical concentrations were identified by fitting segmented polynomial models, including linear-plateau (LP), quadratic-plateau (QP), and rise-to-maximum (EXP) models based on the 95–99% RY criteria. The use of multiple models to determine a range of critical soil-test concentrations is a widely documented approach in nutrient response research (Mallarino, 2003;Clover & Mallarino, 2013). All three models were statistically significant for all soil-test methods ($P \leq 0.001$). All statistical analyses, response-curve fitting, and critical concentration determinations were performed in RStudio version 2025.05.1 (Posit Software, PBC).

RESULTS AND DISCUSSION

Soil-test P&K method comparison

Correlations between soil test P and K analyzed are presented in Figure 1. Soil-test P values measured by BP, M3P-COL, and M3P-ICP ranged from 3 to 69, 3 to 54, and 13 to 127 ppm P, respectively. The strongest relationship was observed between the BP and M3P-COL tests ($R^2 = 0.99$), with a near 1:1 ratio (slope = 0.93). This result is consistent with previous evaluations of soil P tests (Mallarino & Jones, 2018; Jones et al., 2022) and supports the use of the same soil-test interpretations for BP and M3P-COL in several north-central states. In contrast, the M3P-ICP test showed weaker relationships with both BP and M3P-COL ($R^2 = 0.60$). Previous research in Wisconsin has shown varying relationships between colorimetric and ICP determined STP for fine and coarse textured soils (Jones et al., 2022). Similarly, correlations between soil K tests showed that STK values measured by M3K and AAK ranged from 51 to 343 and from 48 to 315 ppm K, respectively. The M3K and AAK tests exhibited a strong relationship ($R^2 = 0.96$), also characterized by a near 1:1 ratio (slope = 0.97), comparable to the relationship observed between the BP and M3P-COL phosphorus tests. This relationship is consistent with other North Central states using a single interpretation guideline for both AAK and M3K extracted STK values (Mallarino et al., 2023).

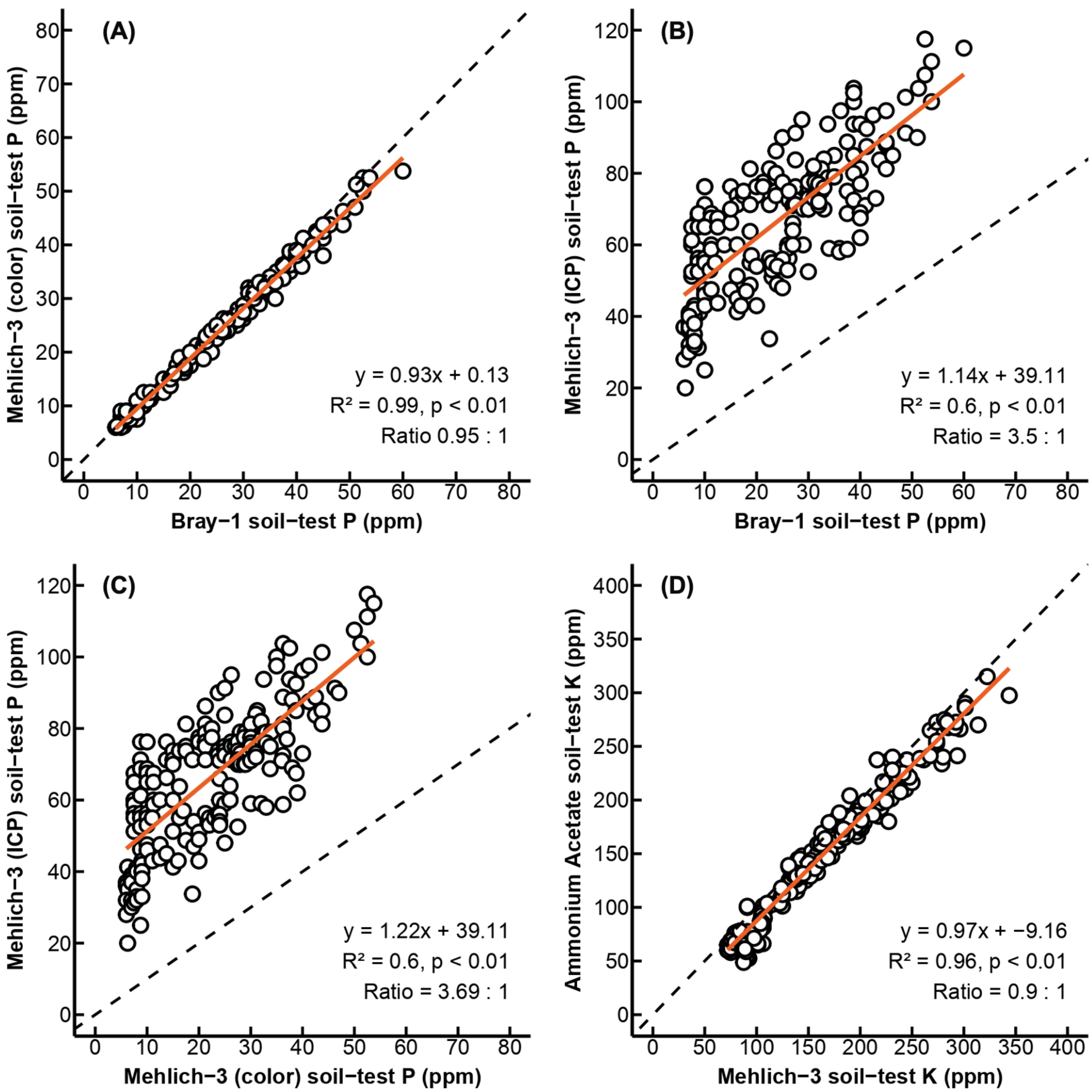

Figure 1. Correlations between the amounts of soil P (A; B; C) and K (D) extracted by the BP, M3P-COL, M3P-ICP, AAK, and M3K methods.

Another comparison among soil-test methods involved evaluating the seasonal variation of soil-test P and K values for the M3P-COL and M3K methods (Figure 2). Results showed similar patterns for both nutrients, with soil-test P and K values being higher in the spring sampling than in the fall. These findings are consistent with previous research (Breker, 2017; Murrell et al., 2021), which has documented seasonal variability in nutrient extraction associated with nutrient losses from crop residues and the influence of rainfall (Rosolem & Steiner, 2017). This pattern further reinforces the importance of standardized sampling and soil-test calibration research procedures to minimize variability when determining appropriate P and K fertilization rates.

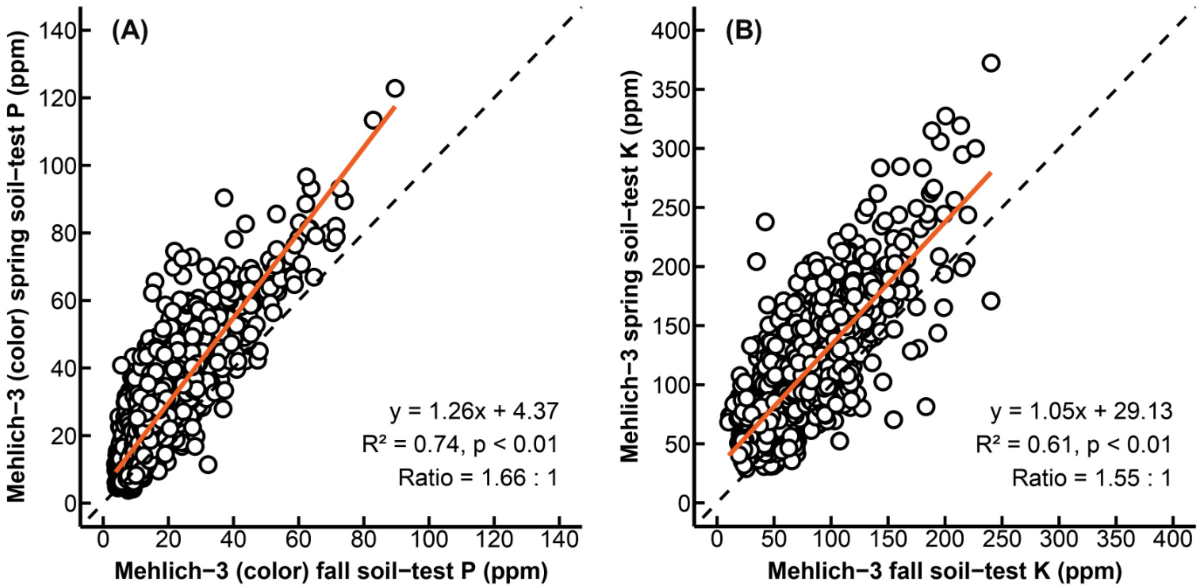

Figure 2. Correlations between the amounts of soil P (A) and K (B) extracted by the M3P-COL and M3K methods during fall and spring samplings at same field trials.

Correlation and identification of critical soil test ranges

Only field correlation of the M3P-COL and M3K tests from fall-collected samples are shared in this paper. Correlation and calibration of all aforementioned tests is being completed, however, insufficient site-years of analysis are completed to date. Figure 3 shows relationships between corn and soybean relative grain yield response to P and soil-test P measured using the M3P-COL method. Relative yield increased (e.g., the response to fertilization decreased) as soil-test P increased, although the goodness of fit varied among specific models and soil-test procedures. The M3P-COL test indicated critical concentration ranges of 10–16 ppm P, which are lower, but similar, than the P critical concentrations reported in other Midwestern states (Jones et al., 2022; Mallarino, 2023). Although the values observed in this study are broadly consistent with previous reports, continued refinement of these critical concentrations will require additional multi-site and multi-year data that reflect current high-yielding cropping systems. It is important to note that model fitting is only one of multiple criteria for critical concentration selection, and additional evaluations of probabilities of fertilizer response, and economic break-even analysis should also be considered.

Figure 4 shows the relationship between relative yield for corn and soybean and soil-test K measured using the M3K method. The critical concentration (CC) range estimated for the M3K test was 109–183 ppm K (Figure 5). In this case, the CC values were higher or similar than those reported in other Midwestern studies (Barbagelata & Mallarino, 2013;

Jones et al., 2022). Our preliminary results vary slightly from current Illinois guidelines developed by Dr. Roger Bray (Bray, 1945).

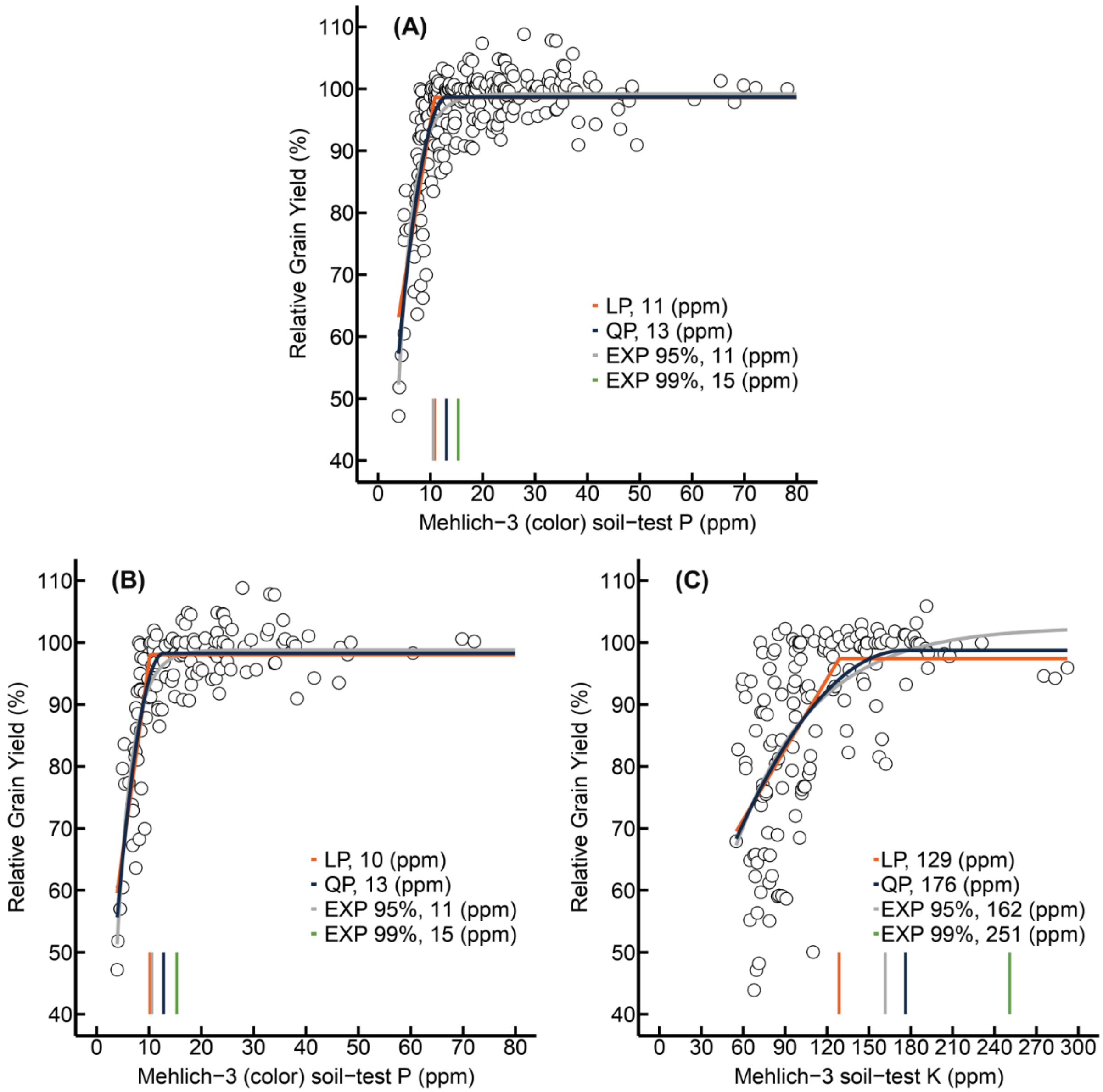

Figure 3. Relationship across all trials and years between corn and soybean (A), only corn (B) and only soybean (C) yield response to P and soil-test M3P-COL (ppm). LP, linear-plateau; QP, quadratic-plateau; EXP, exponential rise-to-maximum model at 95-99 relative grain yield (%). All models significant at $p \leq 0.01$.

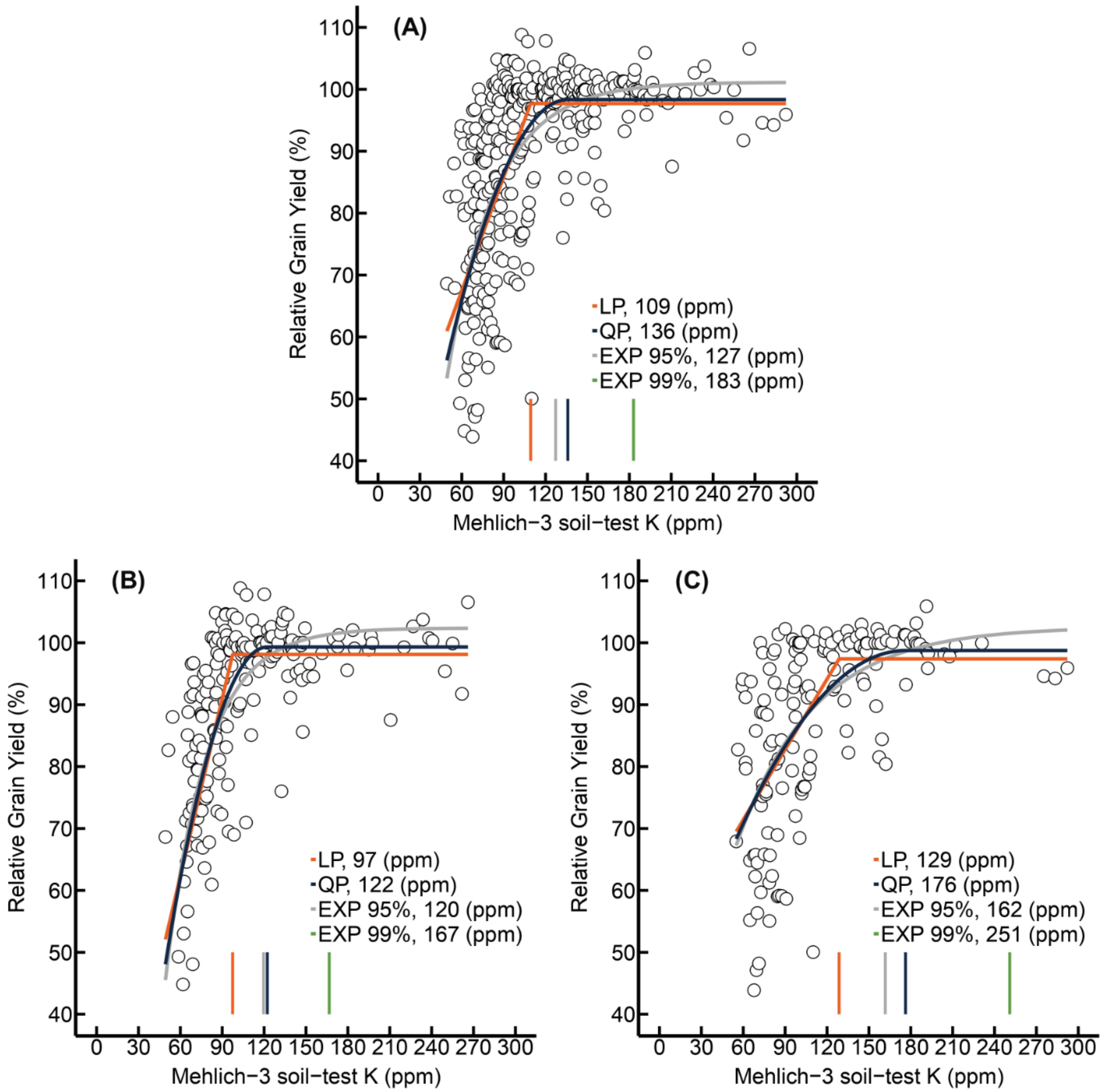

Figure 4. Relationship across all trials and years between corn and soybean (A), only corn (B) and only soybean (C) yield response to K and soil-test M3K (ppm). LP, linear-plateau; QP, quadratic-plateau; EXP, exponential rise-to-maximum model at 95-99 relative grain yield (%). All models significant at $p \leq 0.01$.

Rate response and calibration for optimum P&K rates

The phosphorus rate–response results are presented in Figure 5. For each rate–response trial, an ANOVA was conducted to classify sites as responsive or non-responsive to P fertilization. In responsive sites, the control plots averaged 9 ppm and 8 ppm of P (M3P-COL) for corn and soybean, respectively. Regression models indicated maximum yield response in corn at P application rates between 33 and 44 lb P_2O_5 ac^{-1}, whereas soybeans showed maximum response at rates between 65 and 107 lb P_2O_5 ac^{-1}. These results are consistent with those reported in other Midwestern states (Slaton, 2011; Mallarino, 2023) indicating a high probability of crop response to P fertilization in fields where soil-test P values fall below the critical concentration. The large differences between corn and soybean optimum rates may be biased to the larger corn dataset, however, clear soybean P response indicates the importance of considering soybean P demand, regardless of when P fertilization takes place in the rotation.

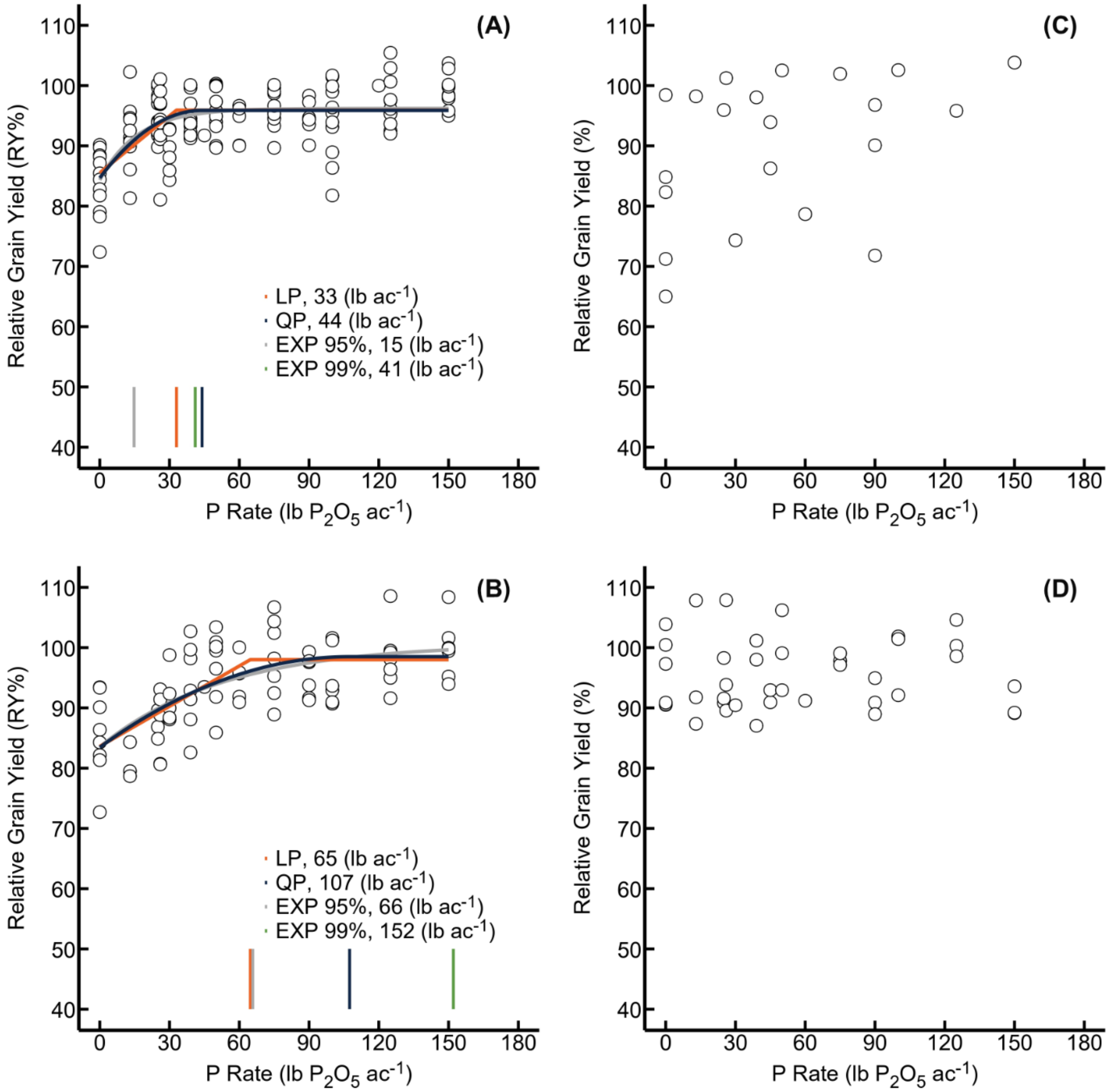

Figure 5. Relationship across all trials and years between corn (A) and soybean (B) yield response to P fertilizer and their non-responsive sites (C; D). LP, linear-plateau; QP, quadratic-plateau EXP, exponential rise-to-maximum model at 95-99 relative grain yield (%).

The same methodology was applied to the potassium rate–response results presented in Figure 6. In responsive sites, the control plots averaged 55 ppm and 47 ppm K (M3K) for corn and soybean, respectively. Regression models indicated maximum yield response in corn at application rates between 70 and 78 lb K_2O ac^{-1}, whereas soybean showed maximum response at rates between 45 and 89 lb K_2O ac^{-1}. Although a clear yield response to K fertilization was detected, the mean values of maximum response for both crops were lower than those reported in the literature for similar high-productivity field conditions. It is important to note that these optimum rates are singularly focused on yield response, and do not include a “build” component, as many state guidelines, including Illinois, do.

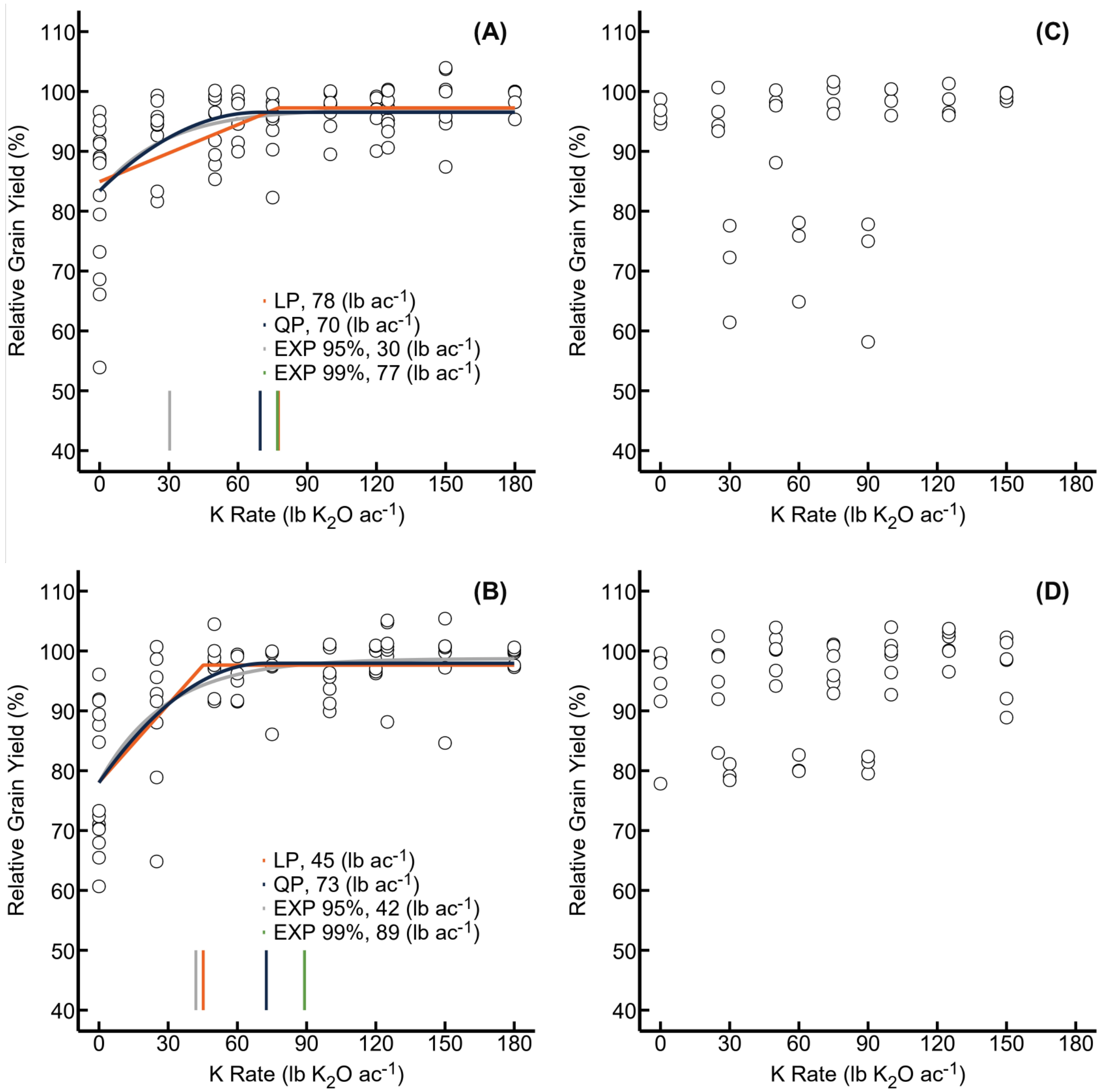

Figure 6. Relationship across all trials and years between corn (A) and soybean (B) yield response to K fertilizer and their non-responsive sites (C; D). LP, linear-plateau; QP, quadratic-plateau; EXP, rise-to-maximum model at 95-99 relative grain yield (%).

Comparison of broadcast TSP and banded APP 10-34-0

An additional analysis performed in this study evaluated the effects of fertilizer application timing, placement, and P source. Figure 7 illustrates the comparison between broadcast-applied TSP and banded ammonium polyphosphate (APP). For each treatment, an analysis of variance (ANOVA) was conducted using a significance threshold of $p < 0.01$. Although these results are preliminary, they provide evidence that may contribute to improved understanding of fertilizer management practices interaction with initial soil-test value and warrant further investigation.

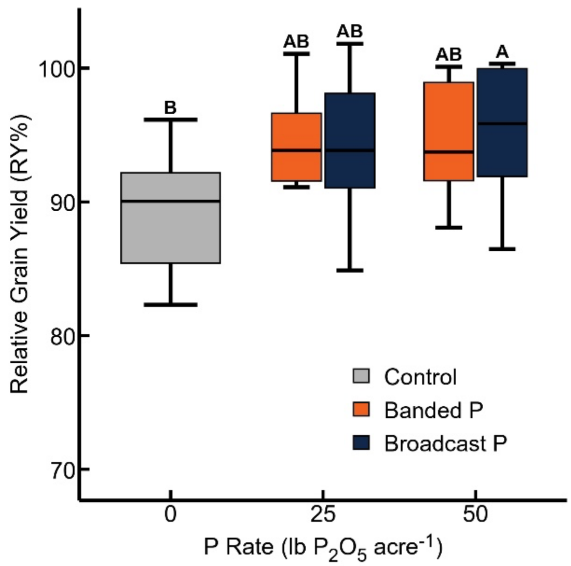

Figure 7. Comparison of broadcast and banded P applications on relative grain yield. Different letters denote significant treatment differences according to ANOVA ($p \leq 0.01$).

First, only responsive sites were included in the analysis. Across these sites, the mean STP concentration was 9 ppm (M3P-COL), indicating a very low initial soil fertility status. This condition aligns with the findings of Bordoli & Mallarino (1998) and Kaiser et al. (2025), who reported that yield responses to P fertilization, including those associated with different placement strategies and fertilizer sources, occur predominantly under very low or low STP conditions. While the cost of different phosphorus sources varies, additional research is needed to characterize the yield response across a broader range of STP levels and to better quantify the role of these fertilizer sources in both maintenance and build-up (STP construction) management strategies.

Second, starter fertilizer affected relative grain yield only when broadcast P was not applied. The greatest increase was observed at the lowest broadcast rate (25 lb P_2O_5 ac^{-1}); however, yield at this rate did not differ statistically from the other broadcast or band-applied fertilizer rates, despite a visually apparent curvilinear trend across the fertilizer gradient. Although further research across additional sites and years is needed, the results presented here indicate that under conditions of low STP and compared to small broadcast phosphorus application rates, starter fertilization could partially offset limited soil P availability.

CONCLUSIONS

This study demonstrated strong agreement among commonly used P and K soil-test extractants and identified critical concentration ranges of 10–16 ppm for M3P-COL and 109–183 ppm for M3K. These findings suggest that P thresholds are generally consistent with regional benchmarks, whereas K thresholds may exceed current Illinois guidelines and merit further validation. Yield responses to fertilization were observed primarily under low soil-test conditions, underscoring the importance of soil-test–based, site-specific decision making. Under depressed commodity price conditions, strategies that emphasize maintaining soil-test levels near the lower end of the critical ranges and prioritizing fertilization in confirmed responsive fields could be explored as potentially cost-efficient options, subject to further economic analysis. Continued multi-site, multi-year research will be necessary to refine and validate these recommendations for modern Illinois production systems.

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