UPDATING SOIL-TEST PHOSPHORUS AND POTASSIUM GUIDELINES IN ILLINOIS: FIELD CORRELATION AND CALIBRATION FOR CORN AND SOYBEAN

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ABSTRACT

University of Illinois soil-test phosphorus (P) and potassium (K) recommendations require reevaluation to reflect changes in soil-testing practices, crop production systems, and fertilizer economics. This study evaluated soil-test P and K relationships with corn and soybean yield responses across multiple field trials in Illinois to refine critical concentrations and fertilizer recommendations. Strong relationships were observed among commonly used soil-testing methods, particularly between Bray-1 and Mehlich-3 colorimetric P, while seasonal differences highlighted the importance of sampling time for soil-test interpretation. Field correlation and calibration analyses identified estimated critical concentration ranges of 15-20 ppm for Mehlich-3 colorimetric P (M3P-COL) and 120-160 ppm for Mehlich-3 K (M3K), generally consistent with current Illinois Agronomy Handbook recommendations. Yield responses to P and K fertilization were primarily associated with low soil-test concentrations, with response probabilities decreasing as soil-test values increased. Fertilizer rate-response analyses indicated that greater nutrient application rates were generally required to maximize relative yield under low soil-test conditions. For observations with soil-test values below the critical range, estimated agronomic optimum rates were 49 and 68 lb P_2O_5 ac^{-1} for corn and soybean, respectively, and 72 and 74 lb K_2O ac^{-1} for the same crops. Economic analyses indicated that positive returns were predominantly associated with soil-test concentrations below 18 ppm for P and 135 ppm for K, both within the estimated agronomic critical ranges. Although positive yield responses may occur above these concentrations, they do not necessarily result in positive economic returns. Overall, these findings highlight the importance of integrating soil-test calibration, fertilizer rate-response relationships, and economic considerations to develop more practical and profitable P and K fertilization strategies for Illinois corn and soybean production systems.

INTRODUCTION

Soil fertility research has a long history in Illinois, with pioneering contributions from Dr. Roger H. Bray during the 1940s helping establish the foundations of modern soil testing and fertilizer recommendations throughout the state and across the Midwest (Bray, 1945). Although recommendations have evolved over time, some of the scientific principles underlying current Illinois phosphorus (P) and potassium (K) guidelines can be traced back to that early research (Fernández & Hoeft, 2009). Since then, corn and soybean production systems have changed considerably, with improvements in crop genetics, increased yield potential, and nutrient use efficiency. Soil-testing practices

have also evolved, particularly with the increasing adoption of Mehlich-3 extraction by commercial laboratories, influencing soil-test interpretations and fertilizer management decisions for producers.

In the context of these changes, several states across the North Central region have made substantial progress in soil-test correlation and calibration research, leading to updated critical soil-test concentrations and fertilizer recommendations for P and K in Iowa, Wisconsin, and Minnesota (Jones et al., 2022; Kaiser et al., 2023; Mallarino et al., 2023). These regional advances highlight the value of continued field research to reevaluate soil-test interpretations and fertilizer recommendations in Illinois under current production conditions.

To address this need, the objectives of this study are to: (1) reevaluate critical soil-test P and K concentrations for corn and soybean across routine soil-testing methods and separately for fall and spring sampling to support revisions to the Illinois Agronomy Handbook; (2) calibrate P and K fertilizer rate recommendations based on soil-test concentrations and relevant soil properties; and (3) evaluate the economic return of P and K fertilization across soil-test concentrations to support nutrient management decisions.

MATERIALS AND METHODS

Site Descriptions and Management

Field experiments were conducted at 17 locations in Illinois and two locations in southern Wisconsin from 2022 to 2026. Multiple trials were established at some locations, resulting in 110 site-years for P and 80 site-years for K (254 and 341 site x year x soil-test level combinations, respectively). Trials encompassed 16 soil series representatives of major Illinois cropland soils, with textures ranging from loamy fine sand to silty clay loam. Soil organic matter ranged from 1.8 to 5.0%, while soil pH varied from acidic to slightly alkaline.

All trials followed a randomized complete block design (RCBD) with four replications. Fertilizer treatments consisted of either (i) a full factorial arrangement of P and K rates or (ii) independent P and K rate treatments, with rates ranging from 0 to 150 lb P_2O_5 ac^{-1} and 0 to 180 lb K_2O ac^{-1}, respectively, both applied in increments of 30 lb ac^{-1}. Phosphorus was applied in the fall following soil sampling as triple superphosphate (0-46-0), while K was applied as potassium chloride (0-0-60). Trials followed a corn-soybean rotation, with both crops grown annually at most locations in separate trials. Conventional tillage was used at most sites, while four sites per year were managed under no-till conditions.

Soil samples were collected in the fall and spring at a depth of 7 inches and analyzed for P using Bray-1 (BP), Mehlich-3 colorimetric (M3P-COL), and Mehlich-3 inductively coupled plasma (M3P-ICP) methods. Soil K was determined using Mehlich-3 (M3K) and ammonium acetate (AAK) extractions. Soil pH (1:1 soil-to-deionized-water ratio), Sikora buffer pH, and soil organic matter (loss-on-ignition method) were also determined for most samples. Soil analyses followed procedures recommended by the North Central Regional Research Committee on Soil Testing and Plant Analysis (Frank

et al., 1998). Laboratory analyses were conducted at the University of Wisconsin-Madison Soil and Forage Analysis Laboratory, while selected samples were analyzed at Radicle Lab® (Radicle Agronomics, Precision Planting, AGCO Corp.) using Microflow technology, which determines soil chemical properties through a slurry-based analytical method.

Statistics and Data Analysis

Grain yield data were analyzed independently for each trial and year using analysis of variance (ANOVA), accounting for the randomized complete block design, to evaluate differences among fertilizer treatments. Model assumptions were assessed through residual diagnostics, including evaluations of normality and homogeneity of variance. Treatment means were compared using Fisher's Least Significant Difference (LSD) test at a significance level of $\alpha = 0.05$. Relative yield (RY) was calculated using the statistically maximum yield (StatMAX) approach described by Pearce et al. (2022), dividing the mean yield of the unfertilized treatment by the mean yield of the statistically maximum-yielding treatment for each site-year and multiplying by 100.

Regression analyses were conducted to evaluate relationships among soil-test extraction methods for P and K. Soil-test calibration was performed by relating the RY of the unfertilized control treatment to soil-test concentrations. Linear-plateau (LP) and quadratic-plateau (QP) models were fitted to estimate critical soil-test concentrations, with model performance evaluated using the coefficient of determination (Adjusted R^2) and Akaike Information Criterion (AIC). The breakpoints estimated by both models were used to establish a range of critical concentrations, following approaches previously reported in soil-test calibration research (Clover & Mallarino, 2013; Mallarino, 2003). All statistical analyses and regression modeling were performed using RStudio version 2025.05.1, Build 513 (Posit Software, PBC).

RESULTS AND DISCUSSION

Soil-test P&K method comparison

Current Illinois fertilizer guidelines provide critical soil-test values for P using BP and M3P-COL methods, and for K using AAK and M3K methods. However, commercial soil-testing laboratories frequently report results using different analytical methods, particularly for P, where M3P-ICP is the most common P test used in the U.S. (The Fertilizer Institute, 2026). To address these differences, regression equations have been developed to convert soil-test values from one method to another. Although these equations provide a way to compare analytical methods, Mallarino (2003) reported that the absolute differences between M3P-ICP and M3P-COL measurements were not correlated with soil P concentrations, highlighting the potential limitations of relying solely on conversion equations.

To evaluate the consistency among these methods, relationships between soil-test measurements were examined across study locations (Figure 1). For P, soil-test values ranged from 3 to 125 ppm for BP, 4 to 130 ppm for M3P-COL, and 6 to 142 ppm for M3P-ICP. The strongest relationship was observed between BP and M3P-COL (R^2 = 0.99), with a near 1:1 relationship (slope = 1.01). This result is consistent with previous

evaluations of soil P tests (Jones et al., 2022; Mallarino & Jones, 2018) and supports the use of similar soil-test interpretations for BP and M3P-COL, as adopted in several North Central states. In contrast, M3P-ICP showed weaker relationships with both BP and M3P-COL (R^2 = 0.55 and 0.53, respectively). Previous research in Wisconsin has also reported differences in the relationships between M3P-COL and M3P-ICP depending on soil texture, particularly between fine- and coarse-textured soils (Jones et al., 2022).

For K, soil-test values ranged from 51 to 347 ppm for M3K and from 47 to 316 ppm for AAK. A strong relationship was observed between M3K and AAK (R^2 = 0.96), with a near 1:1 relationship (slope = 0.93). These findings are consistent with the use of common soil-test interpretation guidelines for AAK and M3K in other North Central states (Mallarino et al., 2023).

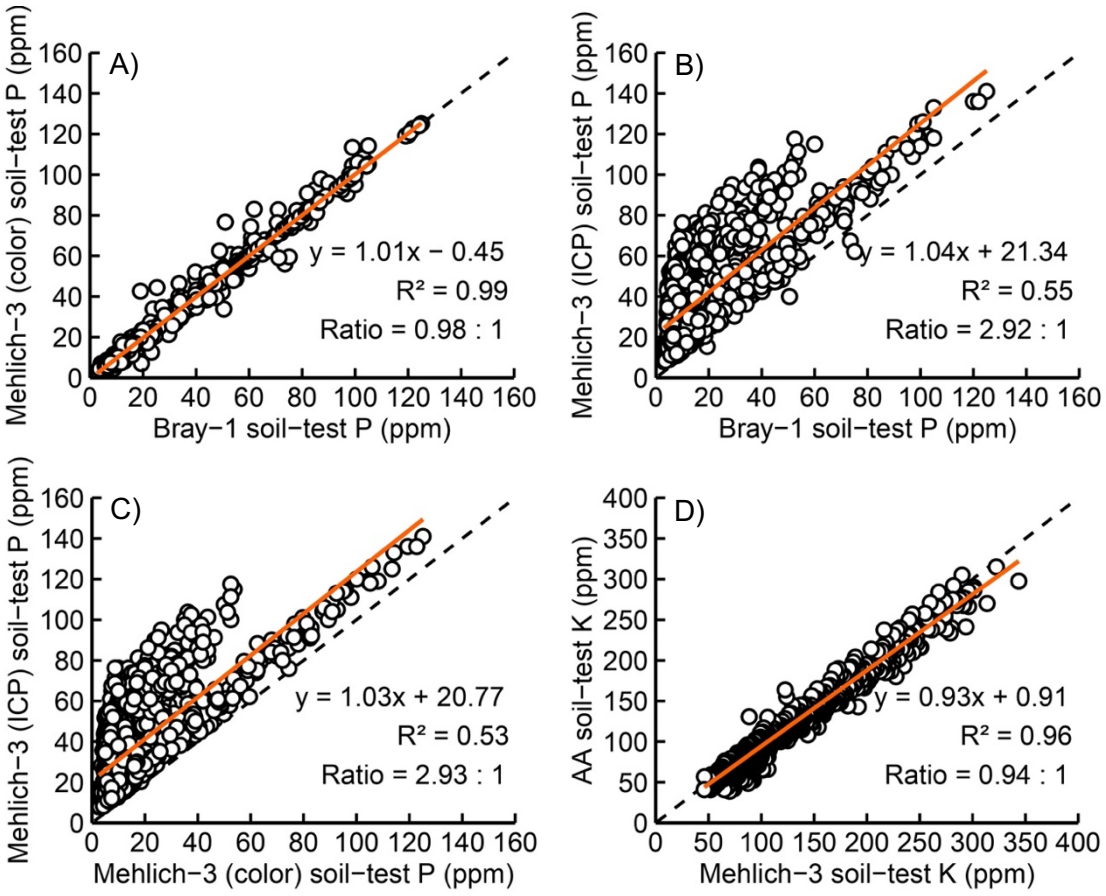


Figure 1. Correlations between the amounts of soil P (A; B; C) and K (D) extracted by the BP, M3P-COL, M3P-ICP, AAK, and M3K methods.

In addition to differences among analytical methods, seasonal variation in soil-test values may also influence soil-test interpretations and fertilizer recommendations. To evaluate these differences, fall and spring soil-test values were compared for both P and K across study locations using M3P-COL and M3K methods, considering only control plots without fertilizer applications (Figure 2).

Results showed similar seasonal patterns for both nutrients, with higher soil-test P and K values observed in spring than in fall. These findings are consistent with previous research (Breker, 2017; Murrell et al., 2021), which documented seasonal variability in soil-test values potentially associated with nutrient release from crop residues and rainfall patterns (Rosolem & Steiner, 2017). Additionally, the dry conditions experienced during recent fall seasons in Illinois may have influenced K retention and release by phyllosilicate expanding clay minerals, potentially contributing to seasonal differences in soil-test K values. Similarly, higher soil-test P concentrations in spring may be partially explained by crop P uptake during the growing season, which can reduce extractable soil P concentrations toward fall. Previous studies have also reported seasonal fluctuations in soil-test P, suggesting that changes in soil P availability and the balance between crop uptake and P release from less-available soil pools may contribute to these differences (Lockman & Molloy, 1984; Lamb and Rehm, 2002). These findings highlight the importance of consistent soil-sampling practices when interpreting soil-test P and K concentrations.

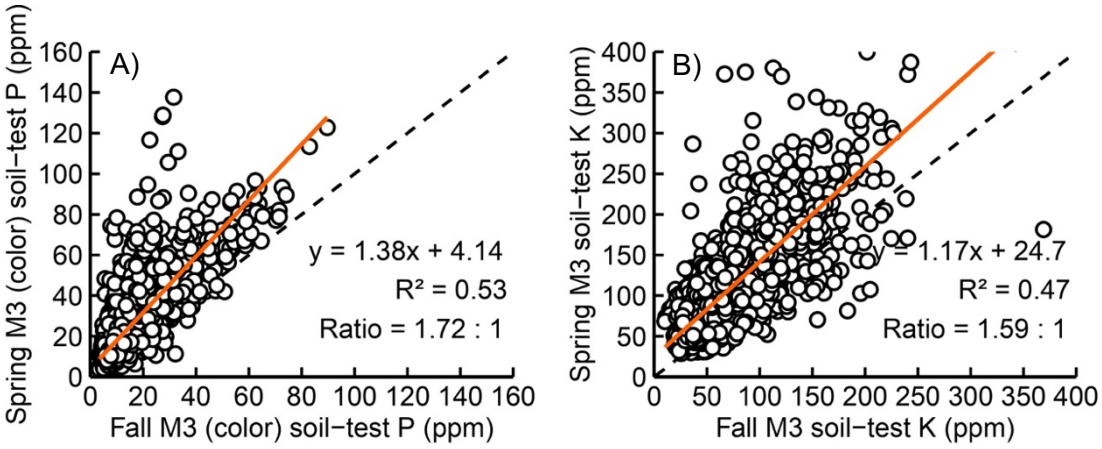


Figure 2. Correlations between the amounts of soil P (A) and K (B) extracted by the M3P-COL and M3K methods during fall and spring samplings at the same field trials.

Correlation and identification of critical soil test ranges

For the soil-test calibrations presented here, only M3P-COL and M3K measurements from fall-collected soil samples were considered to compare with current Illinois Agronomy Handbook values. Correlation and calibration analyses for the remaining soil-testing methods and sampling seasons are still ongoing as additional site-year data are being processed.

Figure 3 shows the statewide relationships between relative grain yield and soil-test P and K concentrations. For both nutrients, relative yield generally increased with increasing soil-test concentrations, indicating a decreasing likelihood of yield response to fertilization. For P, the M3P-COL test indicated a critical concentration range of 15-20 ppm, similar to values reported in other Midwestern states (Jones et al., 2022; Mallarino et al., 2023). For K, the estimated critical concentration range using M3K was 120-160 ppm, with values generally similar to or higher than those reported in other Midwestern studies (Barbagelata & Mallarino, 2013; Jones et al., 2022).

Overall, these preliminary results suggest that the estimated critical ranges are generally consistent with current Illinois soil-test guidelines, which indicate critical concentrations of 15-23 ppm for P and 130-150 ppm for K (Fernández & Hoeft, 2009). However, the wider range estimated for K suggests that further evaluation may be needed to improve soil-test interpretations under current production conditions.

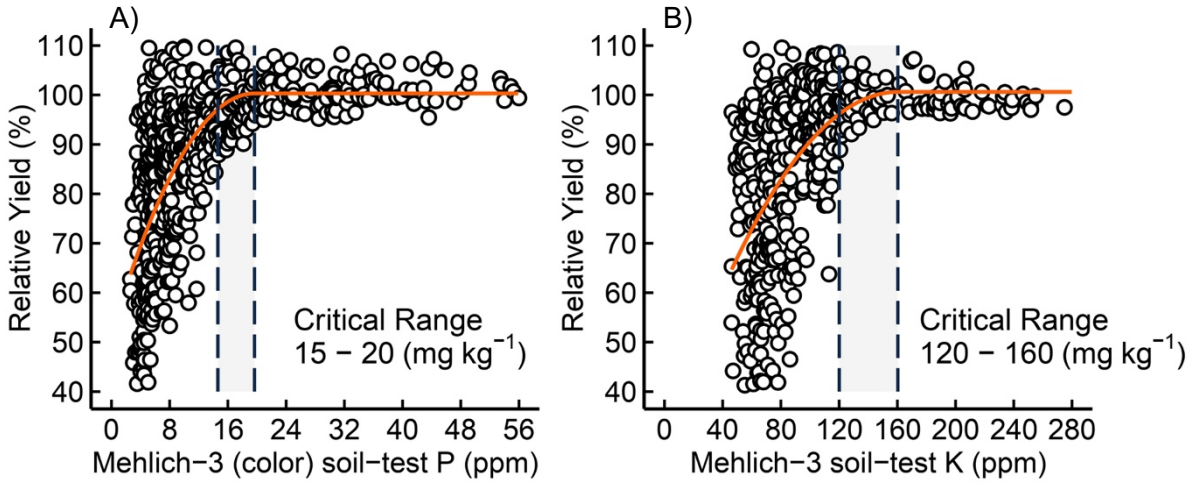


Figure 3. Relationships across all trials and years between relative grain yield (%) and soil-test P (A) measured using M3P-COL and soil-test K (B) measured using M3K, both expressed in ppm. All models were significant at $P \leq 0.05$.

Beyond the overall calibration results, differences in soil properties, particularly subsoil P supply and cation exchange capacity (CEC), may help explain variation in critical soil-test concentrations. Historically, Illinois fertilizer guidelines have established different critical soil-test P concentrations based on low, medium, and high subsoil P supply, while soil-test K recommendations have been differentiated according to CEC values below and above 12 meq 100 g^{-1}.

For P, critical concentrations decreased with increasing subsoil P supply (Figure 4). Soils classified as having low subsoil P supply exhibited the highest critical range (24-31 ppm), followed by soils with medium (13-19 ppm) and high (10-14 ppm) subsoil P supply. Similarly, K critical ranges differed according to CEC classification (Figure 5), ranging from 142 to 184 ppm for soils with CEC below 12 meq 100 g^{-1} and from 119 to 135 ppm for soils with CEC at or above 12 meq 100 g^{-1}. The K results contradict the expected directional relationship between CEC and critical STK. This may be due to the much larger proportion of site-years in the subset of the database from sites above 12 meq 100g^{-1}, or the strong responsiveness of the southern Illinois sites to applied K. Subsoil properties and clay mineralogy analyses will be conducted to a depth at three feet for each site and may provide explanation once completed.

Although these classifications provide a useful framework for interpreting soil-test results, further research is needed to better understand the role of soil mineralogy in P and K availability. Future investigations will focus on refining methods for classifying soils according to subsoil P supply and evaluating whether the current CEC threshold of 12 meq 100 g^{-1} remains appropriate for differentiating soil-test K critical concentrations.

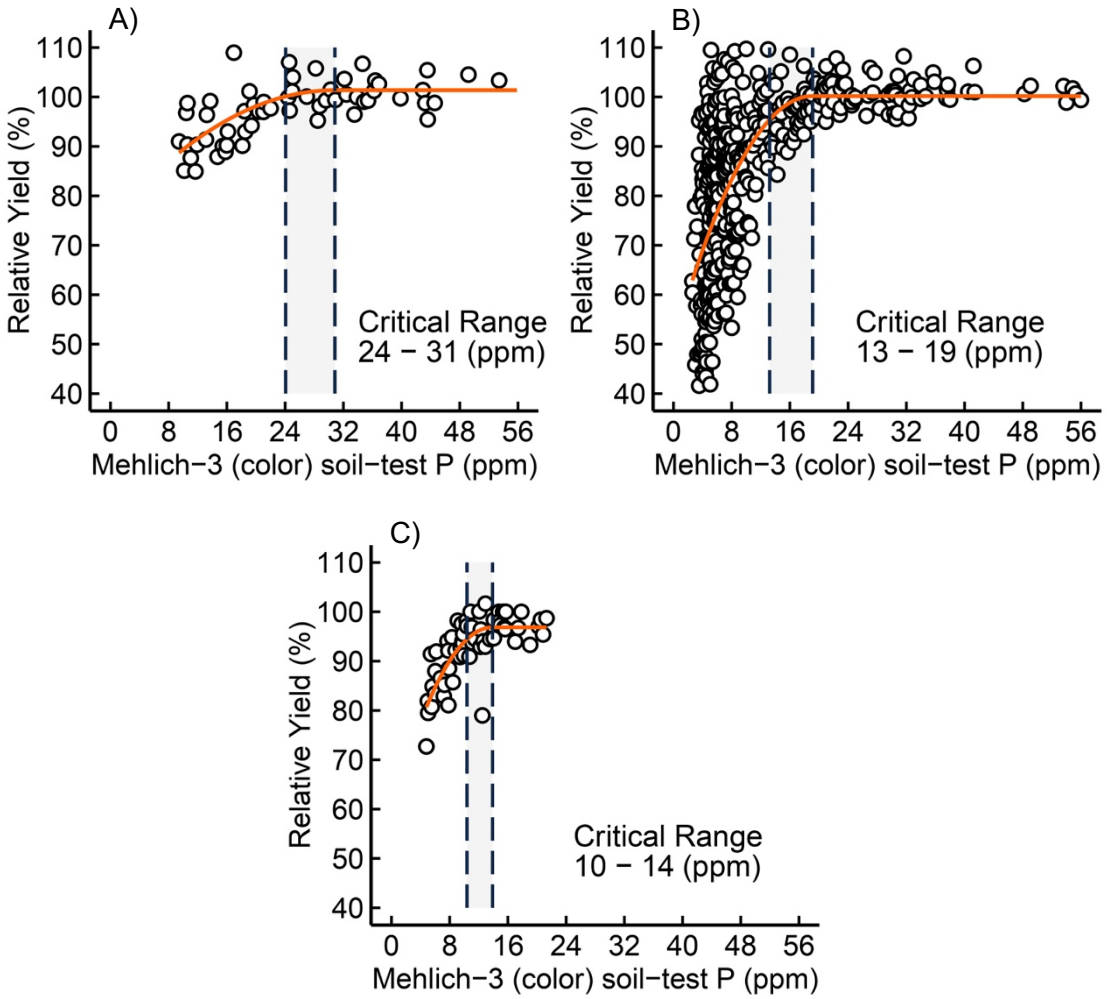


Figure 4. Relationships across all trials and years between relative grain yield (%) and soil-test P measured using M3P-COL for soils classified as having low (A), medium (B), and high (C) subsoil P supply, expressed in ppm. All models were significant at $P \leq 0.05$.

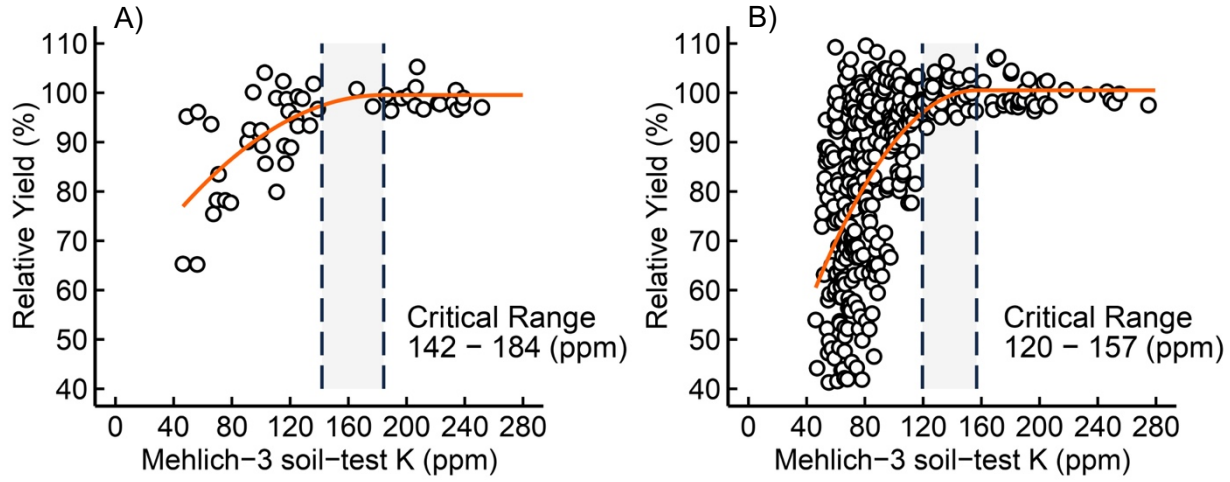


Figure 5. Relationships across all trials and years between relative grain yield (%) and soil-test K measured using M3K for soils with cation exchange capacity (CEC) below 12

meq 100 g^{-1} (A) and at or above 12 meq 100 g^{-1} (B), expressed in ppm. All models were significant at $P \leq 0.05$.

In addition to the estimated critical ranges, the probability of crop response to P and K fertilization was evaluated using the cumulative frequency of unfertilized observations with relative yield below 95% that were responsive to fertilizer using initial ANOVA (Figure 6). For both nutrients, the estimated probability of response decreased with increasing soil-test concentrations. For P, probabilities of 75, 50, and 25% were associated with M3P-COL concentrations of 8, 11, and 15 ppm, respectively. Similarly, for K, these probabilities corresponded to M3K concentrations of 74, 94, and 119 ppm. Together, these findings provide useful information for producers to assess the likelihood of crop response and guide P and K fertility management strategies.

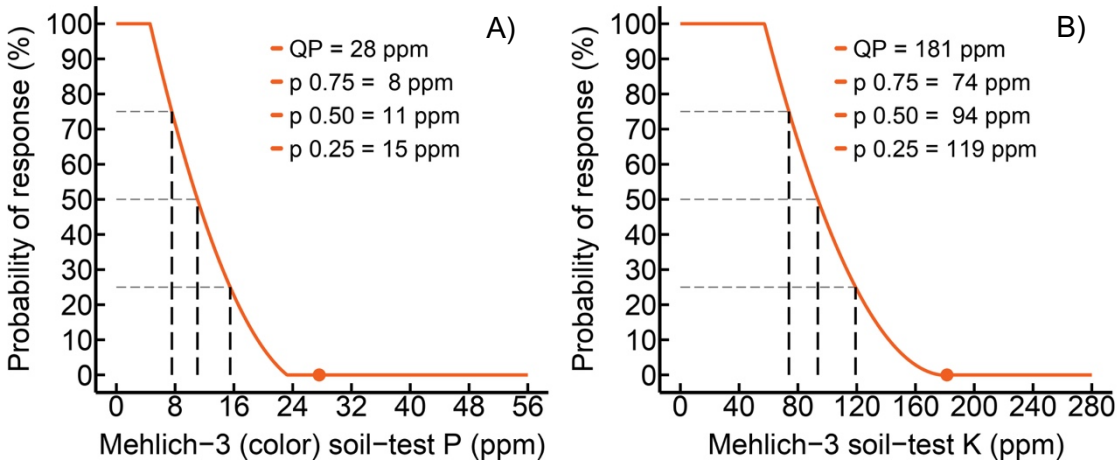


Figure 6. Probability of crop response to P (A) and K (B) fertilization across soil-test concentrations measured using M3P-COL and M3K, respectively, both expressed in ppm. Probabilities were estimated using the cumulative frequency of unfertilized observations with relative yield below 95%. Dashed lines indicate soil-test concentrations associated with 75, 50, and 25% probabilities of response.

Rate response and economic analysis for optimum P&K rates

Following soil-test correlation, fertilizer rate-response analyses were conducted to further evaluate P and K fertilization requirements across a range of soil-test concentrations. While soil-test correlation identifies critical concentrations associated with crop yield response, calibration rate-response analyses provide additional information on how fertilizer application rates influence RY across different soil-test values.

The results of these analyses are presented in Figures 7 and 8 for P and K, respectively. Generalized additive models (GAMs) were used to describe RY as a function of initial soil-test concentrations and fertilizer application rates. The resulting contour plots illustrate predicted RY across combinations of soil-test concentrations and fertilizer rates, with contour lines representing equal levels of predicted RY.

For both P and K, the models indicate that greater fertilizer application rates are required to achieve higher RY at lower soil-test concentrations, whereas the predicted

benefit of additional fertilization generally decreases as soil-test concentrations increase. However, some yield responses to fertilization were still observed at higher soil-test concentrations.

To complement these findings, separate fertilizer rate-response models were fitted to estimate the application rates associated with maximum predicted RY for corn and soybean using observations with soil-test values below the critical range. The estimated agronomic optimum rates for P were 49 and 68 lb P_2O_5 ac^{-1} for corn and soybean, respectively, while the corresponding rates for K were 72 and 74 lb K_2O ac^{-1}. These estimates provide an overall indication of fertilizer requirements for soils below the critical range, complementing the GAM analyses by quantifying fertilizer rates associated with maximum predicted RY. These findings are consistent with the general principles of soil-test calibration and previous research in other states (Mallarino et al., 2023; Slaton, 2011).

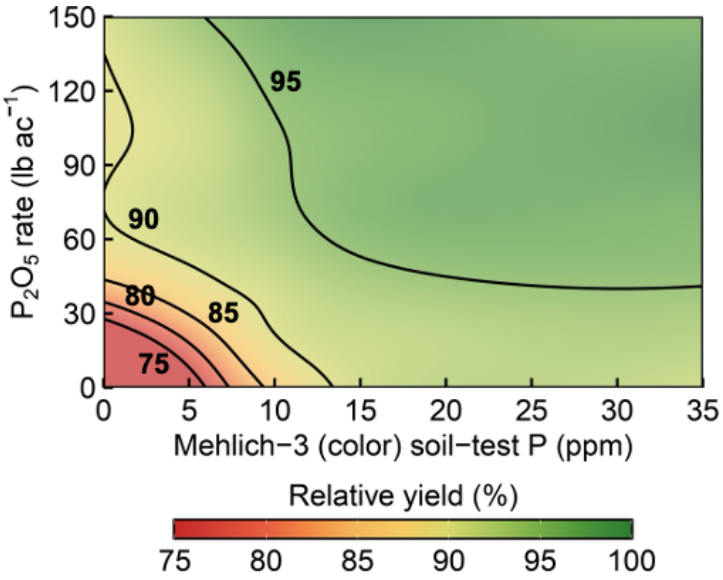


Figure 7. Predicted relative yield (RY, %) as a function of initial soil-test P concentration (M3P-COL, ppm) and P fertilizer application rate (lb P_2O_5 ac^{-1}).

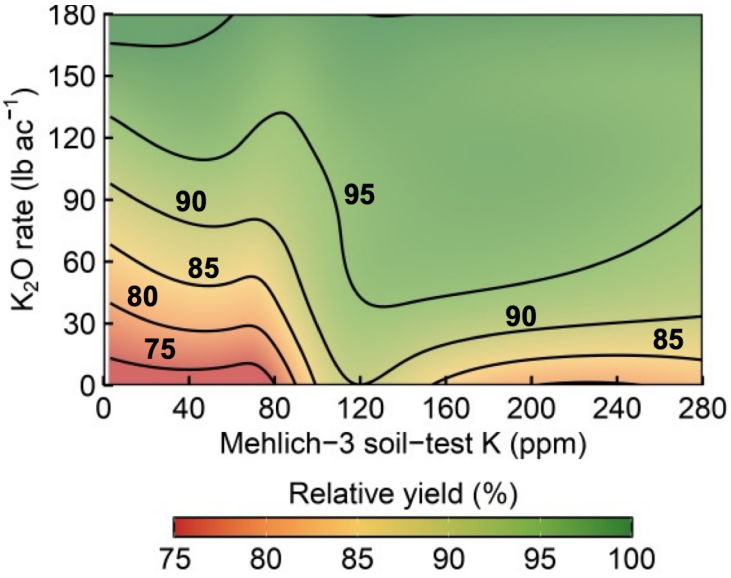


Figure 8. Predicted relative yield (RY, %) as a function of initial soil-test K concentration (M3K, ppm) and K fertilizer application rate (lb K_2O ac^{-1}).

To further evaluate the economic implications of P and K fertilization, a return on investment (ROI) analysis was conducted using grain yield differences, fertilizer application rates, grain prices, and fertilizer costs. ROI ($ ac^{-1}) was calculated by multiplying the difference between maximum statistical yield and observed grain yield by the corresponding grain price, and subtracting the fertilizer application cost, calculated as the fertilizer application rate multiplied by the fertilizer price per unit of nutrient. Fertilizer prices corresponded to November 2026, using monoammonium phosphate (MAP) for P and potash for K, based on DTN Retail Fertilizer Trends (Quinn, 2026). Corn and soybean prices were based on December 2026 futures prices.

Figure 9 presents the economic results for P and K. For both nutrients, calculated economic values generally decreased as soil-test concentrations increased, with positive values occurring predominantly below the statewide critical concentrations of 18 ppm for P and 135 ppm for K. Above these concentrations, economic values were generally negative. These values fall within the critical ranges estimated from the soil-test calibration analyses, indicating general agreement between the agronomic and economic analyses.

Although the fertilizer rate-response analyses indicated that positive yield responses to P and K fertilization may still occur above the critical soil-test ranges, these responses do not necessarily translate into positive economic returns. This highlights the importance of considering not only the agronomic benefits of fertilization but also its economic implications when developing soil fertility recommendations. Integrating both approaches provides a more realistic framework for P and K management, helping producers make more informed and economically sustainable fertilizer decisions.

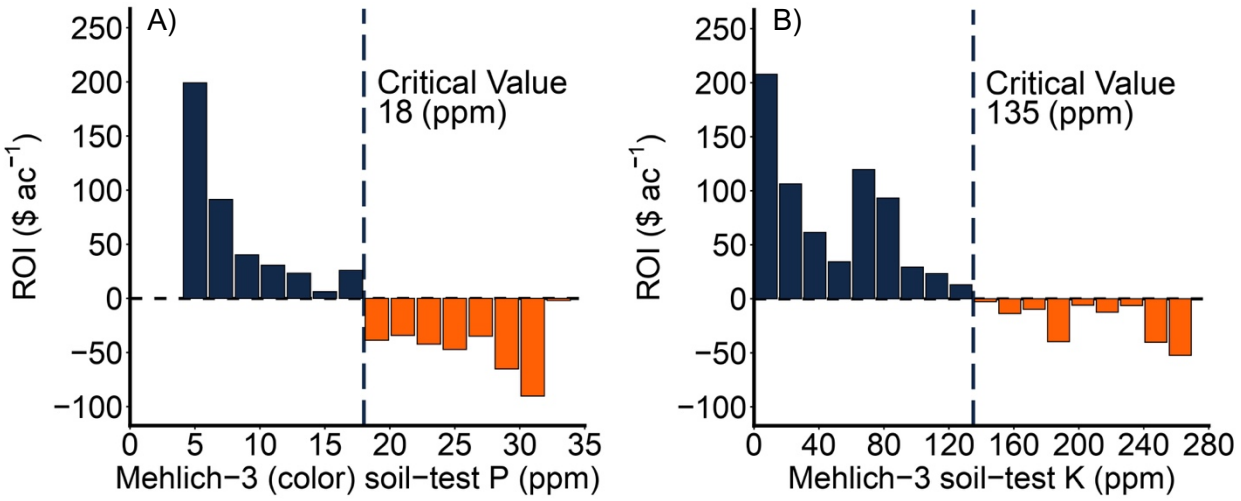


Figure 9. Economic returns ($ ac^{-1}) as a function of initial soil-test P (M3P-COL, ppm; A) and K (M3K, ppm; B) values for corn and soybean. Economic calculations were based on grain prices of $4.45 bu^{-1} for corn and $12.43 bu^{-1} for soybean, and fertilizer prices of $991 ton^{-1} for monoammonium phosphate (MAP) and $504 ton^{-1} for potassium chloride (KCl). Dashed vertical lines indicate the critical concentrations of 18 ppm for P and 135 ppm for K.

CONCLUSIONS

This study demonstrated strong agreement among commonly used phosphorus (P) and potassium (K) soil-testing methods, while highlighting the influence of sampling season on soil-test concentrations. Field correlation and calibration analyses identified statewide critical concentration ranges of 15-20 ppm for M3P-COL and 120-160 ppm for M3K, generally consistent with current Illinois Agronomy Handbook recommendations. These varied by subsoil P supplying power region and CEC designations within Illinois. Yield responses to P and K fertilization were primarily associated with low soil-test concentrations, reinforcing the importance of soil testing for guiding fertilizer decisions. Fertilizer rate-response analyses provided additional information on how crop responses varied with initial soil-test concentrations, while economic analyses showed that positive yield responses do not always translate into positive economic returns. Together, these findings highlight the importance of integrating agronomic and economic considerations to refine fertilizer recommendations and support more profitable nutrient management decisions. Overall, this study provides a foundation for updating soil-test P and K interpretations in Illinois. Continued multi-site, multi-year research and economic evaluation under different price scenarios will be essential to validate critical concentrations, refine fertilizer rates, and develop practical and economically sustainable recommendations for modern corn and soybean production systems.

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