UPDATING SOIL-TEST PHOSPHORUS AND POTASSIUM CALIBRATIONS FOR WISCONSIN

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ABSTRACT

Effective soil-test interpretations and fertilizer recommendations require phosphorus (P) and potassium (K) soil test to be field correlated with crop yield response to fertilization and calibrated to identify response probabilities. Only the Bray-1 soil test is calibrated to provide P and K interpretation guidelines in Wisconsin, with supporting trials being over 30 years old. This study correlated the P extracted by the Bray-1 (BP), Mehlich-3, Olsen-P (OP), and H3A tests and K extracted by the Bray-1 (BK), Mehlich-3 (M3K), ammonium acetate (AAK), and H3A (H3AK) tests with corn and soybean grain yield response to fertilization at 10 Wisconsin sites for a total of 30 site-years. Phosphorus was determined by colorimetric and inductively coupled plasma emission spectroscopy for the Mehlich-3 (M3P-COL and M3P-ICP) and H3A (H3A-COL and H3A-ICP) tests. Sites included six soil series with silty clay loam to sand textures, pH acid to slightly alkaline (6-inch depth), managed with no-till or conventional tillage, and irrigation where required. Amounts of STP measured by BP, M3P-COL, M3P-ICP, OP, H3A-COL, and H3A-ICP were 1-128, 3-142, 8-161, 2-63, 1-76, and 5-94 ppm P, respectively. Amounts of STK measured by BK, M3K, AAK, and H3AK were 2-257, 51-296, 28-311, and 12-132 ppm K, respectively. The current, routine BP best correlated with M3P (R^2 = 0.98) and OP (R^2 = 0.90). The ratio of measured P for BP:M3P and BP:OP was 1.0 and 0.6, respectively.. Soils differing in texture and mineralogy (6-inch depth) showed different relationships between STK methods. Additionally, new STK methods for Wisconsin extracted and measured more or less K compared to the BK test depending on the study site. The M3K test had the strongest relationship with the BK test (R^2 = 0.95), however, it tended to extract more K. The ratio of BK to AAK or H3AK differed by site. Relationships between relative yield response and soil-test by each test and nutrient were described by fitting quadratic-plateau (QP) and linear-plateau (LP) segmented polynomials models. Soil-test CC ranges for both corn and soybean were identified using all models that had significant fit to the data ($P \leq 0.01$). Bray-1 CC range for P and K were 16-23 ppm and 78-116 ppm, which largely agree with current optimum STP and are slightly lower than optimum STK range in Wisconsin Fertilizer Guidelines. The OP, M3P-COL, and M3P-ICP CC ranges were 13-18, 16-24, and 30-43 ppm P, respectively. Ranges of CC for the M3K and AAK were 97-117 and 112-140 ppm K, respectively, and showed more variability than the BP test. For P and K, the H3A test showed high sensitivity to study site and poorer relationships with relative yield. These results are

initial phases in providing interpretation guidance for P and K soil tests, in addition to the Bray-1 test, for Wisconsin that can inform fertilization decisions.

INTRODUCTION

Fertilization guidelines that support crop production and abate nutrient losses require reliable and effective soil-test recommendations. As a diagnostic tool, soil testing provides the framework to which phosphorus (P) and potassium (K) fertilization should be based, and must be field correlated with crop yield response to fertilization and calibrated to identify response probabilities. The small fraction of total soil nutrient concentration measured by each soil test method can vary with soil properties. Each test can provide different interpretation, thus, needing to be individually calibrated when appropriate (Mallarino, 2009). Current P K fertilization guidelines in Wisconsin are solely based on soil-test P (STP) and K (STK) extracted with the Bray-1 solution (Laboski and Peters, 2012). Additionally, field and laboratory research supporting current recommendations are greater than three decades old and require reevaluation.

Private and public soil testing laboratories have moved to multi nutrient extracting solutions such as the Mehlich-3 test for P and K. From 2001 to 2020, the proportion of reported STP values as Mehlich-3 determined by inductively-coupled plasma spectrophotometry (ICP) across the conterminous U.S. has increased to 56% of soil P samples nationwide (Jones et al., 2021). Shifts to tests such as the M3P-ICP provide faster workflow times for soil sample submissions requesting P, K, Ca, Mg, Na, and micronutrients. However, performance of the Mehlich-3 test in certain situations, such as high pH soils (Rutter et al., 2021), has come into question. Additional tests such Olsen P (Olsen et al., 1954) and ammonium acetate K (Frank et al., 1998) have been calibrated in north central states to provide fertilizer recommendations. The Olsen P test is predominately used in regions with high pH soils and ammonium acetate K used nationwide. A soil P and K test component of a soil health assessment tool known as the “H3A test” has recently been used for fertilization decisions by farmers, agronomists, and organizations in the north central region (Hany et al., 2017). Though research in neighboring states have defined critical concentrations for H3A with P (Mallarino and Jones, 2018), there is no guidance for using the H3A method in Wisconsin.

Removal of nutrients during harvest represents the largest consistent mechanism for soil-test levels of P and K to decline below optimum ranges. Across the north central region, crop removal of P and K has increased from 2001 to 2020, with greater K removal than P (Jones et al., 2021). Grain concentration of P and K coupled with yield levels drive removal, but the relationships between soil-test level and increasing yields of corn and soybean on removal require attention. Maintaining optimum soil-test levels by applying removal rates can maximize yields (Mallarino and Prater, 2017) with consideration for grain content and yield level. It is uncertain how increasing or decreasing soil-test and yield levels affect P and k removal, thus, fertilizer needed to maintain optimum P and K levels.

Therefore, the objectives of this study were to: (1) compare the amount of P or K measured with additional tests compared to the routine Bray-1, (2) identify and compare critical soil-test concentrations for all P and K tests, and (3) examine the relationship between soil-test level, crop yield, and harvest grain removal of P and K.

SUMMARY OF METHODS

Field studies were conducted with corn and soybean at 10 Wisconsin sites with multi-year trials from 2021 to 2022. There were 30 site-years for both corn and soybean. Data for trials conducted from 2014 to 2020 are being summarized at this time. Trials included sites with six soil series with silty clay loam to sand textures, pH acid to slightly alkaline (6-inch depth), managed with no-till or conventional tillage, and irrigation where required. All sites included a randomized complete block design with a complete factorial treatment structure of several P (0 to 90 lb P2O5 ac^{-1}) and K (0 to 160 lb K2O ac^{-1}) rates replicated four times. Relative grain yield was calculated for each trial by expressing the mean yield (across replication) without fertilization as the percentage of the mean yield of treatments produced by the statistically maximum yield (the mean of all treatments, including the control, was used as maximum yield when there was no P or K response). This method of relative yield determination is termed "STATMAX" (Pearce et al., 2022). Grain samples were collected from each plot and analyzed for P and K concentration using (Zarcinas et al., 1987). Grain removal of nutrients with harvest was calculated by using the measured nutrient concentration multiplied by the plot-level grain yield and adjusted for consistent moisture.

Soil samples were analyzed for P by the Bray-1, Mehlich-3 (colorimetric), Mehlich-3 (ICP), and Olsen tests following the procedures suggested by the NCERA-13 north-central region soil testing committee (Frank et al., 1998). Soil samples were analyzed for K by the Bray-1, Mehlich-3, and ammonium acetate tests (Frank et al., 1998). Additionally, soil samples were analyzed by the H3A (colorimetric) and H3A (ICP) methods defined by Haney et al. (2017). Laboratory analysis was conducted at AGVISE Laboratories, Northwood, North Dakota.

Regression analysis was used to compare the amounts of P and K extracted by each test across all trials. Relationships between relative yield response and soil-test values for each method were studies across the response trials. Relationships between relative yield and soil-test concentration were studied for each P and K test and a range of critical concentrations for each method were determined by fitting the segmented polynomials linear-plateau (LP) and quadratic-plateau (QP) models. Using multiple models to identify a critical concentration range has been a well-documented method used for both soil nutrient and plant tissue nutrient concentration (Mallarino, 2003; Clover and Mallarino, 2013). Model selection was limited to those which provided a constant slope plateau when analysis of variance (ANOVA) indicated no statistical difference between treatments above the model joint point (the concentration at which the two portions of the LP and QP models join). The LP and QP models determine critical concentrations directly at a 100% sufficiency level. The two models were statistically significant for all methods ($P \leq 0.001$). Relationships between grain nutrient concentration of P and K and crop removal with soil-test level and crop yield were analyzed by fitting linear or curvilinear models. All statistical analysis, response model fits, and critical concentration identification was done in SAS ODA (SAS Institute, Cary, NC).

SUMMARY OF RESULTS

Relationships between Soil Tests

Correlations between the amounts of P measured with BP and other P tests are shown in Figure 1. Amounts of STP measured by BP, M3P-COL, M3P-ICP, OP, H3A-COL, and H3A-ICP were 1-128, 3-142, 8-161, 2-63, 1-76, and 5-94 ppm P, respectively. Study site soil properties (soil texture The BP and M3P-COL tests showed the strongest relationship ($r^2 = 0.98$) with a near 1-to-1 ratio (slope =1.04). This agrees with previous analysis of soil P tests (Mallarino and Jones, 2018), and supports why in other north central states the soil-test interpretations are the same for both BP and M3P-COL tests (Mallarino et al., 2013). The second best relationship ($r^2 = 0.9$) with BP was the OP test (Fig. 1). In general, the OP test extracted one half of the P measured by the BP test, and the relationship had greater variation compared to the M3P test. The relationship between both H3A-COL and H3A-ICP and BP was affected by study site. No effect of study year was observed on regressions between tests. Fine and coarse surface texture soils showed different relationships, with the H3A solution (determined by colorimetric or ICP methods) extracting less P in coarse texture soil (Fig. 1). Samples from coarse surface texture sites additionally had soil organic matter from 0.7 to 1.6% (6-inch), soil pH values of 5.0 to 6.1, and lower P buffering capacities (Laboski and Peters, 2013). The M3P-ICP test had the poorest relationship with the BP test (Fig. 1). Greater amounts of P were extracted by M3P-ICP compared to BP for sites with coarse surface texture. In fine texture soils, there was considerable variation between the ratio of BP to M3P-ICP at BP levels less than 60 ppm P. Figure 2 shows the correlations between all soil K tests investigated. Amounts of STK measured by BK, M3K, AAK, and H3AK were 2-257, 51-296, 28-311, and 12-132 ppm K, respectively. The BK and M3K tests had the strongest relationship across all site-years ($r^2 = 0.95$) with the M3K test extracting 1.2 times more soil K or 24 ppm K on average across the entire study. This ratio is within the range reported by Vitko et al. (2008) on central and eastern Wisconsin soils. Ammonium acetate K showed the poorest relationship with BK ($r^2 = 0.86$), and had a greater error at all BK levels. Relationships between all K tests and the H3AK were best described by separating the fine and coarse texture soils (Fig. 2). The H3AK test had a higher ratio compared to the BK, M3K, and AAK test for coarse soils and poorer for the fine soils.

Determination of Critical Concentrations

Soil-test critical concentrations (CC) are widely agreed to be the soil nutrient level above which crop yield response to fertilization is relatively low (Dahnke and Olsen, 1990).

Figure 4 shows the relationships between corn and soybean relative grain yield response to P with soil-test P measured by all P tests. Relative yield increased (response to fertilization decreased) with increasing soil-test P measured by all methods, but the goodness of fit for some specific models and soil-test methods were better than others. Bray-1 and M3P-COL tests showed similar CC ranges of 16-23 and 16-24 ppm P, respectively (Fig. 4). These ranges are similar to the current Wisconsin optimum interpretation class range for BP of 16-20 ppm P for corn and soybean (Laboski and Peters, 2012). The CC range for the M3P-ICP was 30-43 ppm P. Soil-test P determined with ICP is well reported to be greater than sing colorimetry (Mallarino, 2003), and M3P-ICP was shown to be 22 ppm P greater than M3P-COL in this study. Importantly, simply using the difference in amount of P extracted by the M3P-COL and M3P-ICP would not lead to correct identification of CC ranges and response model joint points. Thus, the need for field calibration studies that use direct laboratory measurements, and not mathematical regression inferences. The CC range defined here is similar to ranges found in Iowa (Mallarino, 2003; Mallarino et al., 2013). Olsen P CC range was 13-18 ppm P. The LP and QP models fit for relative yield and OP had the closest joint point, leading to a narrow CC range of 5 ppm. A more narrow range of CC for the OP test can be expected due to the lower amount of P extracted with the sodium bicarbonate used in the OP test. Lower measured soil-test P values will lead to condensed data points near the CC on a response curve graph (Fig. 4) like for the OP test. The H3A-COL and H3A-ICP test showed CC ranges of 10-17 and 23-29 ppm P, respectively. Recent field correlation studies in Iowa reported slightly lower values (9-13 ppm P) for the H3A-COL test (Jones, 2021). Although CC ranges only provide a point at which to determine to fertilizer or not, farmers and agronomists can use these ranges to guide decisions if only an H3A P test is returned in a soil sample result report.

Figure 5 shows the relationship of relative yield for corn and soybean with soil-test K for all K tests. Corn and soybean yield ranged from 34-285 and 20-111 bu ac^{-1}, respectively, across all site-years. Yield responses to K fertilization were greater and more consistent than responses to P. Potassium fertilization led to increases in corn and soybean yield of 0-260 and 0-48 bu ac^{-1}, respectively. Critical soil-test K concentrations for the BK, AAK, M3K, and H3AK tests were 78-116, 112-140, 97-117, and 30-37 ppm K, respectively (Fig. 5). Models fit for the BK, M3K, and H3AK had much better goodness of fit (R^2 0.83 to 0.97) than the AAK test (R^2 0.66 to 0.68). For all K tests, the QP model had a lower Akaike Information Criteria (AIC), lower values indicate a better likelihood of a good fit to the data, compared to the LP model. The CC determined for BK in this study is lower than the range of 100 to 130 ppm K used in current Wisconsin fertilization guidelines (Laboski and Peters, 2012). Reasons for the discrepancy between this study and current guidelines are complex. Root morphology, planting density, and residue decomposition rates have changed considerably since the original research work to build current guidelines (Kelling et al., 1990). Additionally, current Wisconsin guidelines consider the most limiting crop (requiring the highest STK CC) in a rotation that decide the recommended STK level and K fertilization rate (Laboski and Peters, 2012). The M3K CC range was 97-117 ppm K (Fig. 5). This range had a similar upper limit to the BK test, however, the lower limit of the CC was 18 ppm K lower for the M3K compared to the BK test. On average across the study, the M3K test measured 25 ppm K more than the BK test for a given sample, though as previously discussed the ratio of BK / M3K was smaller at lower STK levels, and decreased with increasing soil pH (Fig. 3), thus, assuming a constant ratio of BK / M3K may be incorrect. This partially explains why the lower CC limit of the M3K test is greater than the BK test, yet as both methods approach values near 100 ppm K or greater (the upper limit of the CC range), the two tests are near similar. The AAK test had the highest range of CC at 122-140 ppm K. Across all soils, the AAK test measured 22 ppm K more than the BK test. No discernable patterns between the ratio of BK / AAK were observed, however the relationship between the BK and AAK test was the weakest correlation of all K tests (Fig. 2). The AAK CC range is slightly higher than those reported in neighboring states like Minnesota () and Iowa () for fine-textured soils. Either model fit the AAK poorer than the other tests. The H3AK test had the narrowest CC range, owing to less K extracted with this method. No published recommendations have used the H3AK method for determining a CC range. The method of interpreting an H3AK soil-test value would not differ from the other K tests. Furthermore, both the LP and QP models best fit for the H3AK test compared to the others tests (R^2 = 0.98). For all K tests, response models well fit the data, allowing for clear determination of CC ranges, and can provide guidance of at what STK values a yield response to fertilization would not be expected.

Grain Concentration and Harvest Removal

Grain nutrient concentration and yield level determine the amount of nutrients removed with crop harvest. Current University of Wisconsin guidelines recommend applying crop removal of P and K when soil-test levels are in the Optimum category (in the CC range) and recommend applying on half of crop removal for the High interpretation class (Laboski and Peters, 2012). Figures 6 to 9 summarize the relationships between P and K grain concentration, removal, soil-test level (Bray-1 test only), and grain yield for corn and soybean separately. Figure 6 shows P grain concentration and removal as a function of BP. For corn and soybean, grain P increased rapidly from lower BP levels to a maximum near an asymptote (Fig. 6). Corn grain P reached an asymptote of 0.33 % at 41 ppm P, while soybean grain P leveled off at 0.7 and 70 ppm P. Removal of P (lb P_2O_5 ac^{-1}) showed varied relationships with BP. Figure 6 differentiates P removal values by STK levels (Bray-1 K). Lower STK levels led to a wider distribution of grain P removal, likely driven by yield response to STK, and demonstrates the need to consider STK levels when attempting to change STP levels. Figure 7 shows the relationships between grain K concentration, K removal, and STK (Bray-1 K). Corn grain K did not have any relationship with BK, however, soybean grain K increased to a plateau of 1.83% K at 101 ppm K (Fig. 7). This plateau BK level is near the center of the determined CC range of 78-116 ppm K, and reaffirms that range as allowing for optimal K supply to reach a maximum grain K content. Unsurprisingly, corn and soybean K removal both had significant relationships with BK ($P < 0.01$), albeit weak coefficients of determinations (r^2 0.23 to 0.28). Removal of K for corn and soybean plateaued at 104 and 93 ppm K, respectively, and was mostly driven by yield increase for corn but both grain K content and yield increases for soybean (Fig. 7).

Figure 8 shows the relationship of grain P and removal P in relation to crop yield. Neither corn or soybean grain P had a significant relationship with yield (Fig. 8), indicating higher or lower yield levels did not influence the P eventually located in the grain. Phosphorus removal showed a strong linear relationship with yield for both corn (r^2 = 0.9) and soybean (r^2 = 0.91). For all data in this study, corn removed 0.31 lb P_2O_5 per bushel yield and soybean removed 0.77 lb P_2O_5 per bushel yield. This indicated that at corn yield values of 100, 175, and 250 bu ac^{-1}, P removal would be 33, 56, and 79 lb P_2O_5 ac^{-1}. Soybean P removal for 50, 75, and 100 bu ac^{-1} yield are 37, 56, and 76 lb P_2O_5 ac^{-1}. Soil-test K level did not affect the relationship between P removal and corn or soybean yield, however the yield level of each crop did vary by STK. Figure 9 shows the relationship between grain K and K removal with yield. Yield level did not affect corn grain K, however, soybean grain K increased with increasing yield up to a plateau of 1.85 % K at 89 bu ac^{-1} soybean yield (Fig. 9). Corn and soybean K removal linearly increased with grain yield, however, soybean had a stronger relationship (r^2 = 0.98). These data suggest that soybean K removal not only increased with yield level due to a greater mass of grain being harvested, but also due to a higher grain K concentration (Fig. 9). Corn yield levels of 100, 175, and 250 bu ac^{-1} led to a K removal of 18, 30, and 42 lb K_2O ac^{-1}, respectively. Soybean yield levels of 50, 75, and 100 bu ac^{-1} led to K removal of 54, 85, and 117 lb K_2O ac^{-1}, respectively. Thus, corn grain removed 0.16 lb K_2O per bushel yield and soybean removed 1.26 lb K_2O per bushel yield (Fig. 9). In crop rotations where corn or soybean are achieving higher yield levels, priority should be given to concerning STK decline after a soybean crop.

CONCLUSIONS

Interpretation guidance for soil P and K test values other than the Bray-1 test have not been previously available in Wisconsin. Critical concentrations for corn and soybean identified using the BP, OP, M3P-COL, M3P-ICP, H3A-COL, and H3A-ICP were 16-23, 13-18, 16-24, 30-43, 10-17, and 23-29 ppm P, respectively. These ranges allow for decisions of at which soil-test P value yield response to P fertilization is expected. Bray-1 and M3P-COL tests had most similar amounts of P measured, and field calibration of CC ranges indicate both tests could inform fertilization decisions using the same interpretation classes currently available for the BP test in Wisconsin. To determine P fertilizer application rates using the M3P-ICP, OP, H3A-COL, or H3A-ICP, additional site-years are necessary and analyses of percent probability of response, which is currently ongoing. Potassium CC range of 78-116 ppm K for the BK test was slightly lower than current University of Wisconsin guidelines. This may indicate a need to refine guidelines to better match current cropping systems in Wisconsin compared to when historical data was collected. Critical STK ranges for the M3K and AAK tests were 97-117 and 112-140 ppm K, respectively. The differences in

M3K CC ranges compared to the BK range were attributed to the M3K test measuring for STK at lower STK levels and as soil pH increases.

Grain P and K content and removal drive fertilization decisions which aim to maintain an optimum soil-test P or K in the critical concentration range. Soybean grain P and K content increased with STP to reach maxima in this study, while only corn grain P content as STP increased. Only K removal showed a significant increasing trend to a maximum while STK increased to 93 and 104 ppm K for corn and soybean, respectively. Neither corn nor soybean grain P or corn grain K content showed a relationship with yield level. Soybean grain K content showed a strong relationship with yield, plateauing at 1.85 % K at 89 bu ac^{-1} yield. Removal of P with harvest linearly related to yield increase with removal values of 0.31 and 0.77 lb P_2O_5 bu^{-1}, for corn and soybean, respectively, with greater P removal generally occurring when STK levels were higher. Potassium removal increased with yield, with corn and soybean removing 0.16 and 1.26 lb K_2O bu^{-1}, respectively. These data suggest that as corn and soybean yields increase over time or with management decisions, increases in soybean yield can proportionally removal more K in a cropping system. Overall, these results provide interpretation guidance for soil-test methods in addition to currently used Bray-1 for P and K fertility management in Wisconsin or similar soils. Additional trials and site-years are currently being analyzed to supplement the data and processes presented.

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References

Clover, M. W., & Mallarino, A. P. (2013). Corn and soybean tissue potassium content responses to potassium fertilization and relationships with grain yield. *Soil Science Society of America Journal*, *77*(2), 630-642.

Dahnke, W.C., & Olson, R.A. (1990). Soil test correlation, calibration, and recommendation. In R. Westerman (Ed.), Soil testing and pant analysis (pp. 45–71). SSSA

Haney, R. L., Haney, E. B., Smith, D. R., & White, M. J. (2017). Removal of lithium citrate from H3A for determination of plant available P. Open Journal of Soil Science, 7(11), 301-314.

Jones, J., Bruulsema, T., Rund, Q., & Tarik, S. (2021). Soil Test Levels to Guide Nutrient Stewardship: Phosphorus and Potassium Focus for the North-Central Region. *Crops & Soils*, *54*(6), 38-45.

Kelling, K., Schulte, E., Bundy, L., Combs, S., Peters, H. (1990). The New Wisconsin Soil test Recommendation Program. In *North-Central Extension-Industry Soil Fertility Conf. Proceedings. Nov* (pp. 136-138).

Laboski, C. A., & Peters, J. B. (2012). Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin (A2809). *Univ. of Wisconsin-Ext., Cooperative Extension. Madison, WI*.

Mallarino, A. P. (2009). Long term phosphorus studies and how they affect recommendation philosophies. In *North-Central Extension-Industry Soil Fertility Conf. Proceedings. Nov* (pp. 14-15).

Mallarino, A., & Jones, J. (2018). Correlation of the Weak Organic Acids Test of a Soil Health Tool with Crop Yield Response to Phosphorus Fertilization. In *Iowa State University. 48th North-Central Extension-Industry Soil Fertility Conf. Proceedings* (Vol. 34, pp. 14-20).

Mallarino, A.P., and J. Prater. (2007). Corn and soybean grain yield, phosphorus removal, and soil-test responses to long-term phosphorus fertilization strategies. p.241-253. In The Integrated Crop Management Conf. Proceedings. Nov. 29-30, 2007. Ames, IA. Iowa State Univ. Extension.

Rutter, E. B., Ruiz Diaz, D., & Hargrave, L. M. (2022). Evaluation of Mehlich-3 for determination of cation exchange capacity in Kansas soils. *Soil Science Society of America Journal*, 86, 146– 156.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. U.S. Government Printing Office, Washington D.C.

Vitko LF, Laboski CAM, Andraski TW (2009) Effects of sampling time, soil moisture content, and extractant on soil test potassium levels. In: Thirty-ninth north central extension-industry soil fertility conference, Des Moines, vol 25, 18–19 Nov 2009. International Plant Nutrition Inst, Brookings, pp 124–132

Zarcinas, B. A., Cartwright, B., & Spouncer, L. R. (1987). Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. *Communications in Soil Science and Plant Analysis*, *18*(1), 131-146.

Tables and Figures

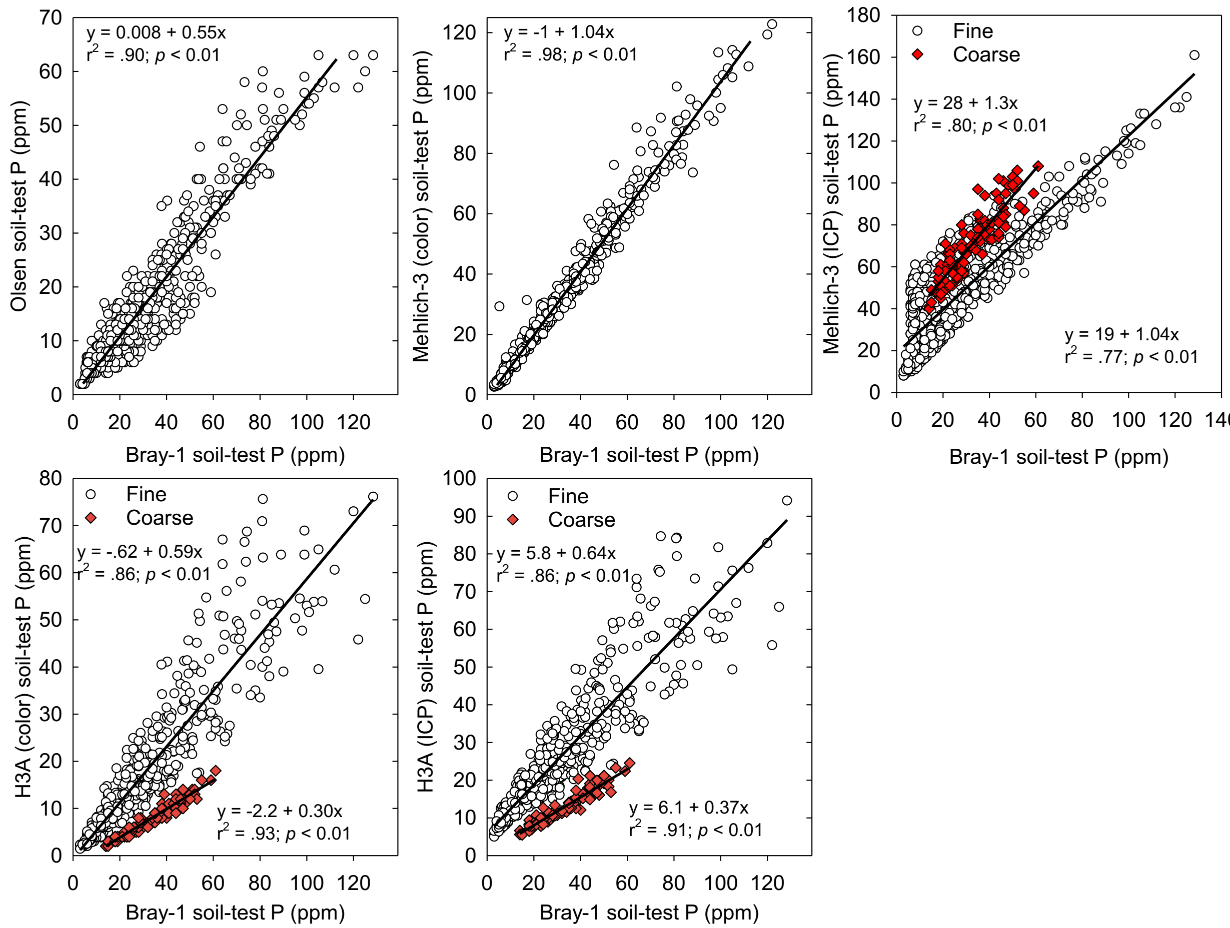

Figure 1. Correlations across all trials and years between the amounts of soil P extracted by the routine BP test and M3P-COL, M3P-ICP, OP, H3AP-COL, and H3AP-ICP methods (means across replications). When appropriate, data are segmented into soils with fine (loamy) and coarse (sandy) surface soil textures (6-inch).

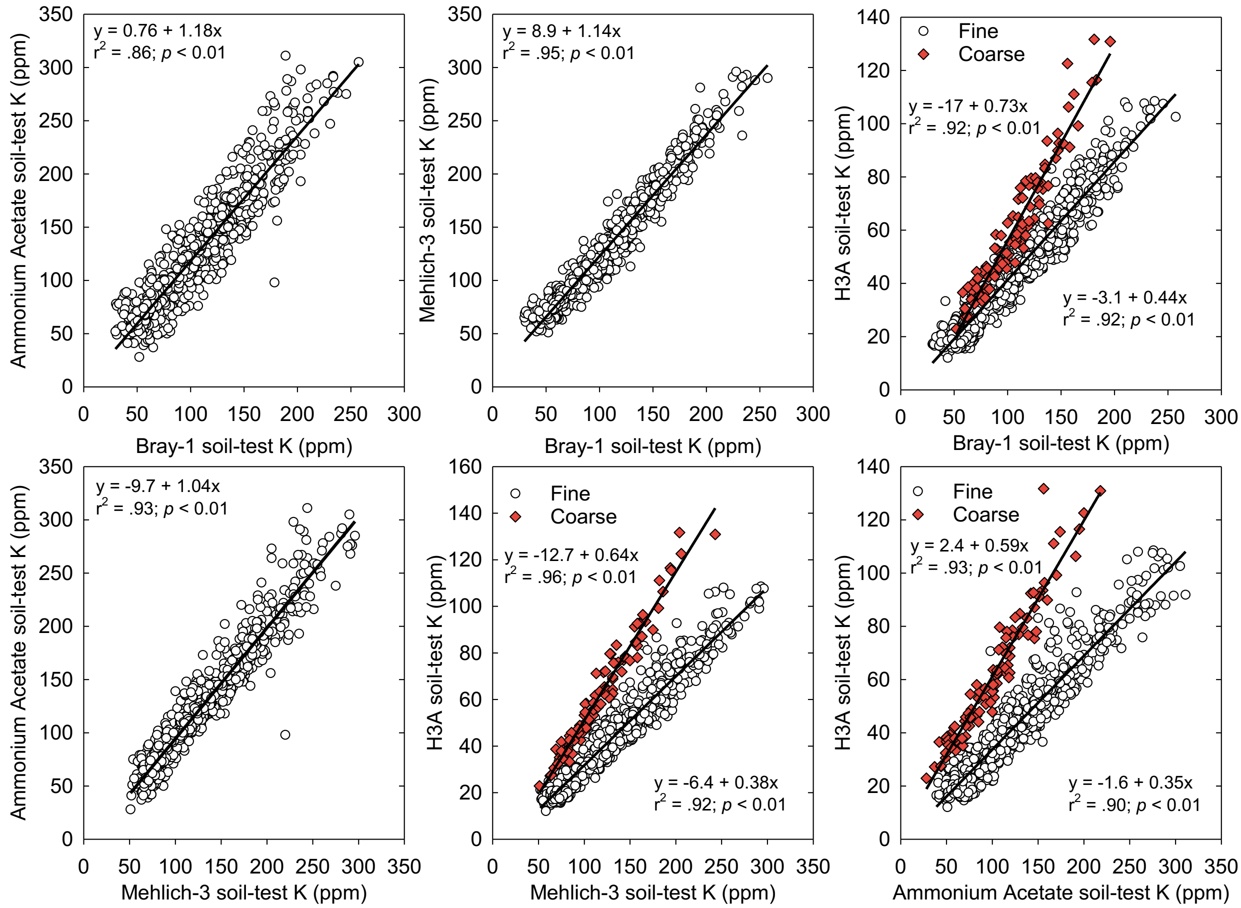

Figure 2. Correlations across all trials and years between the amounts of soil K extracted by the BP M3K, AAK, and H3AK methods (means across replications). When appropriate, data are segmented into soils with fine (loamy) and coarse (sandy) surface soil textures (6-inch).

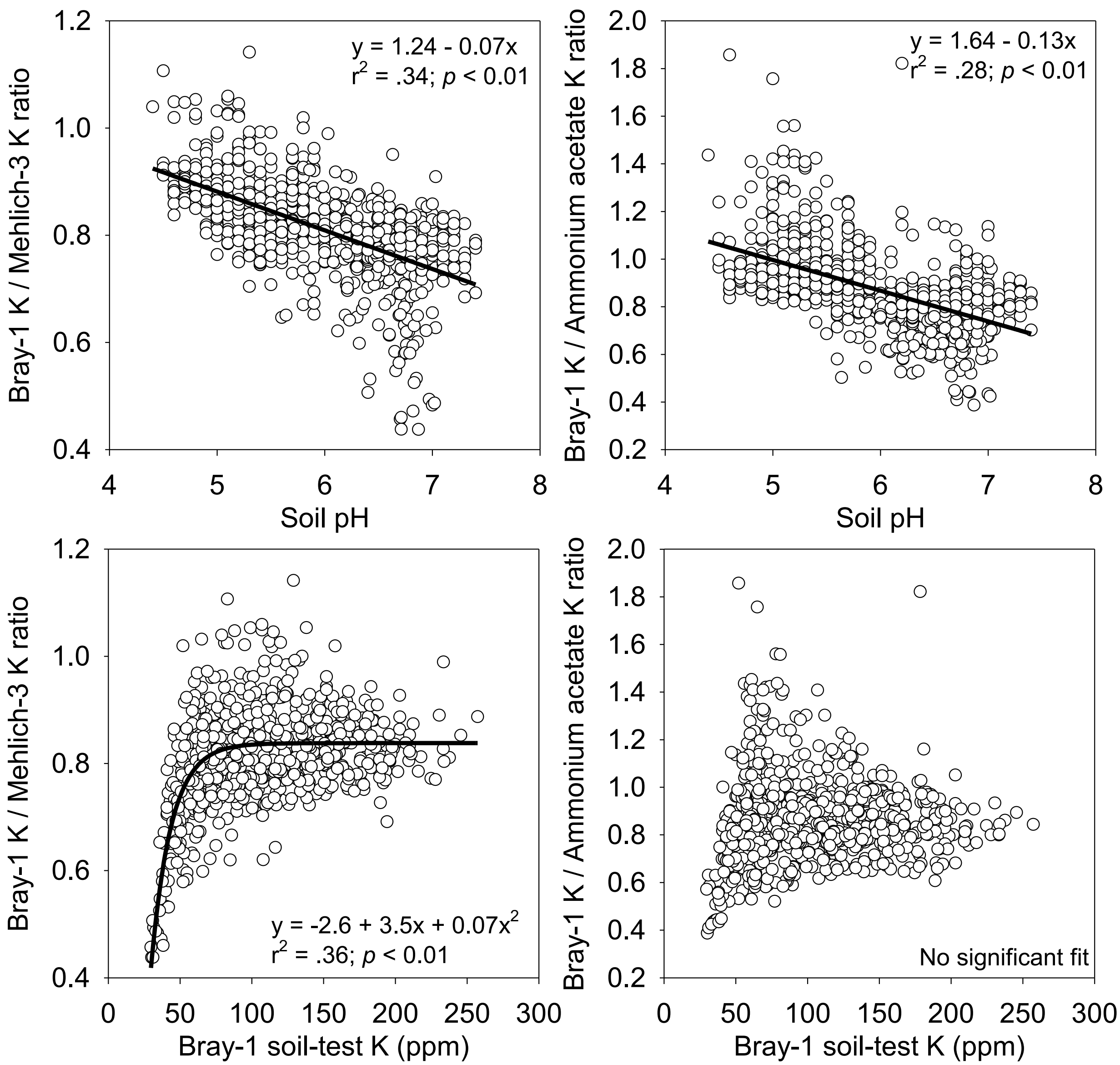

Figure 3. Ratio of Bray-1 to Mehlich-3 and ammonium acetate soil-test K with soil pH and soil-test Bray-1 K levels.

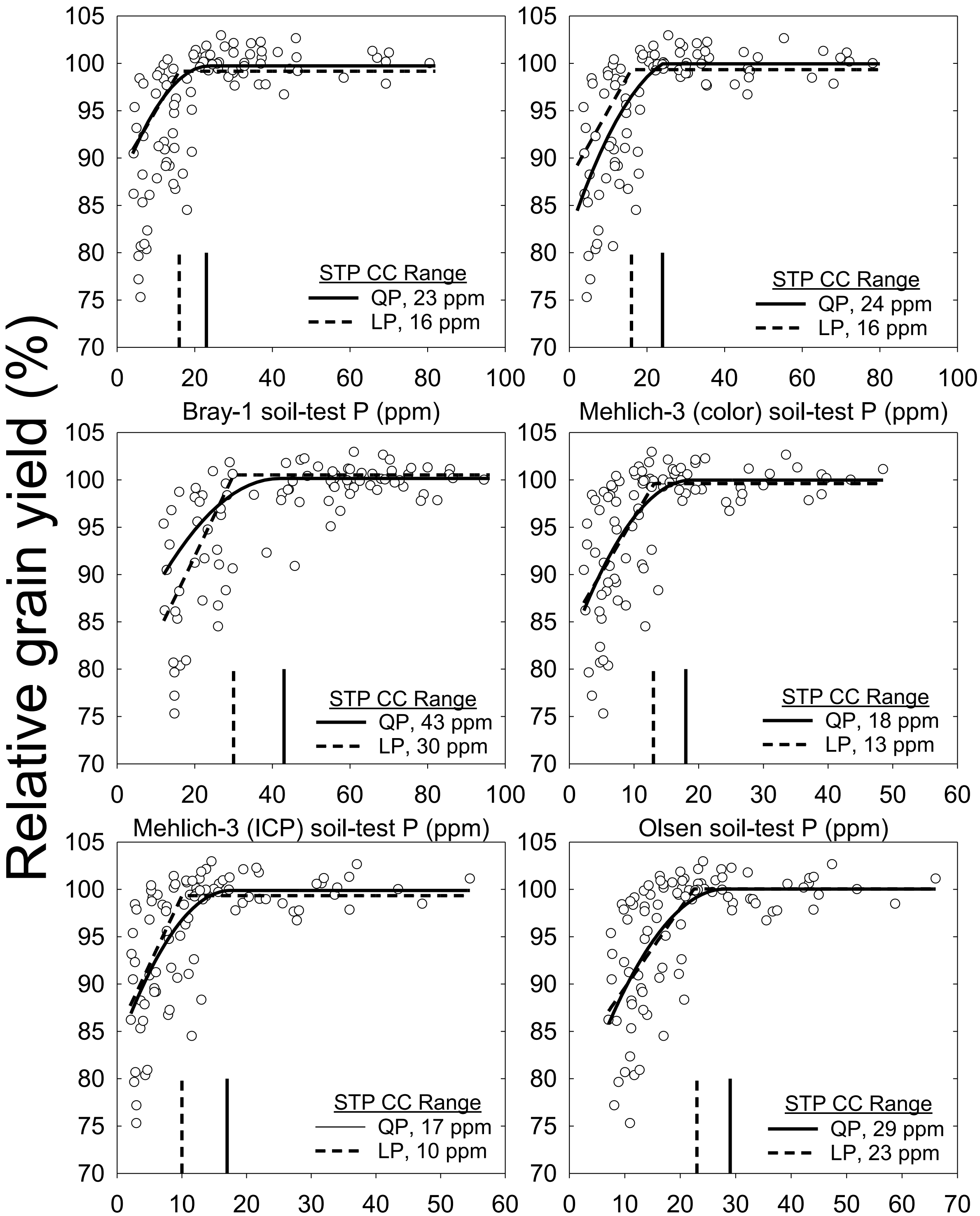

Figure 4. Relationship across all trials and years between corn and soybean yield response to P and soil-test P measured by the six methods. QP, quadratic-plateau model fit and its estimated critical concentration; LP, linear-plateau model fit and its estimated critical concentration.

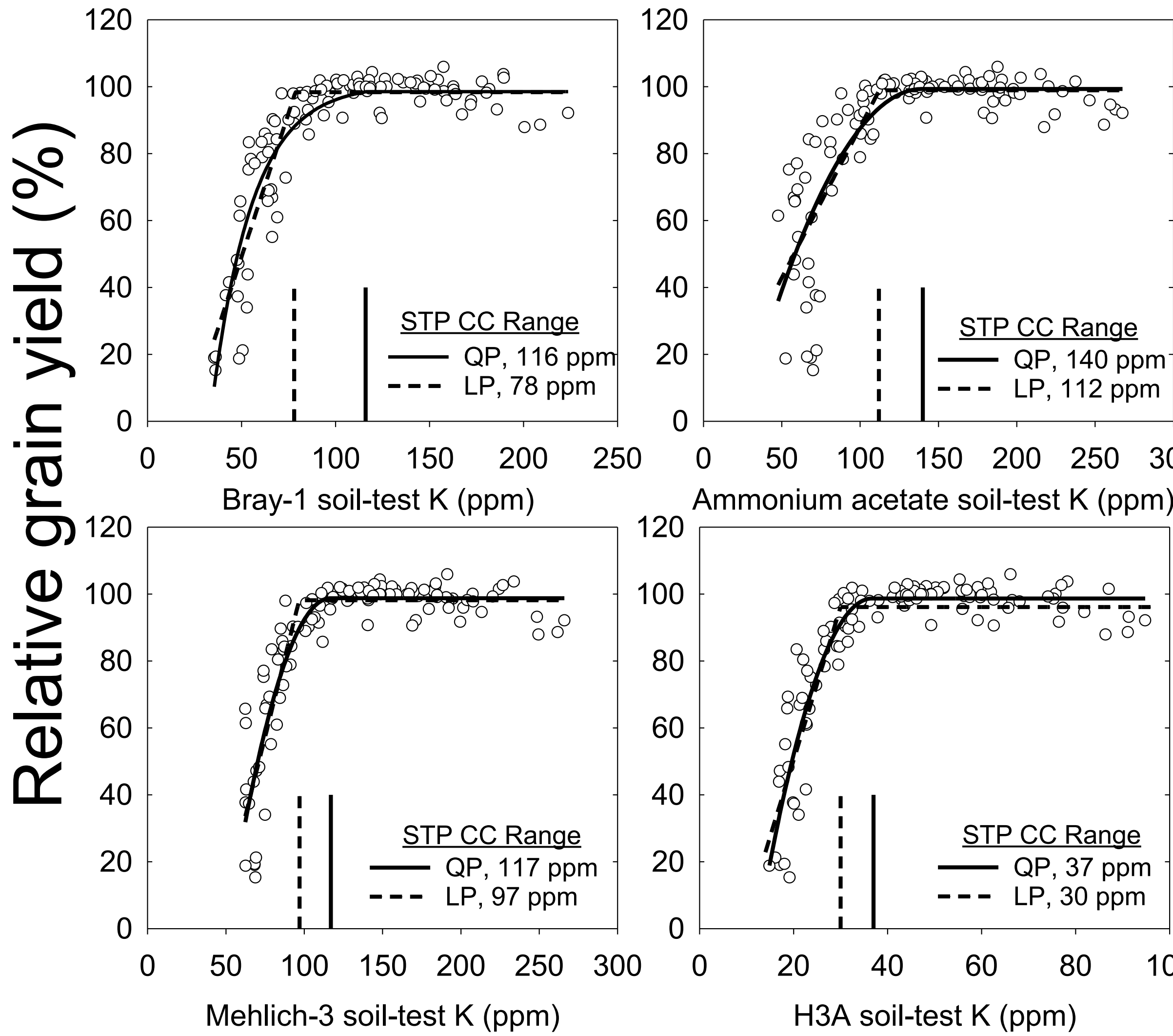

Figure 5. Relationship across all trials and years between corn and soybean yield response to K and soil-test K measured by the four methods. QP, quadratic-plateau model fit and its estimated critical concentration; LP, linear-plateau model fit and its estimated critical concentration.

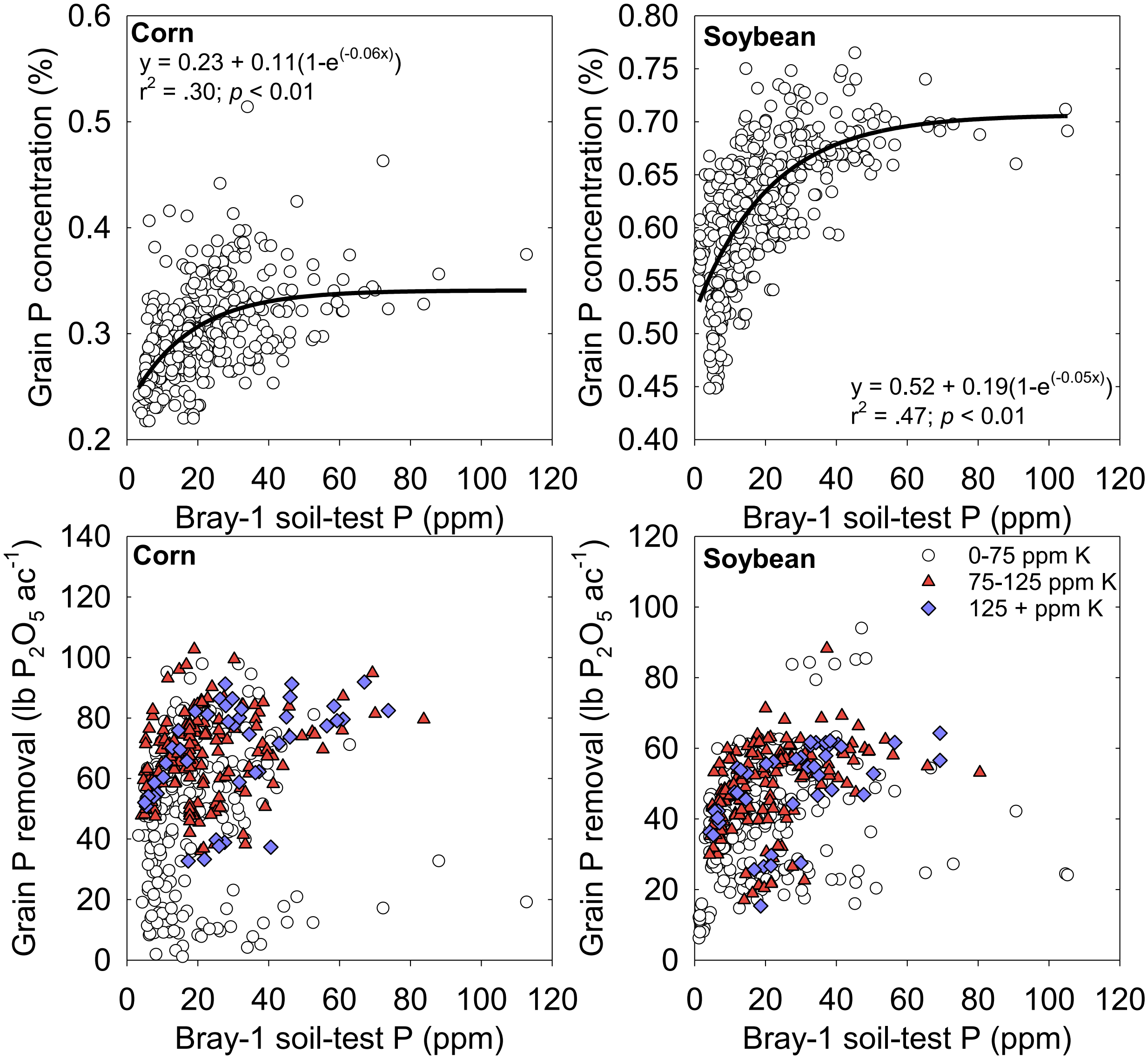

Figure 6. Relationships between Bray-1 soil-test P and grain P concentration and removal with harvest for corn and soybean.

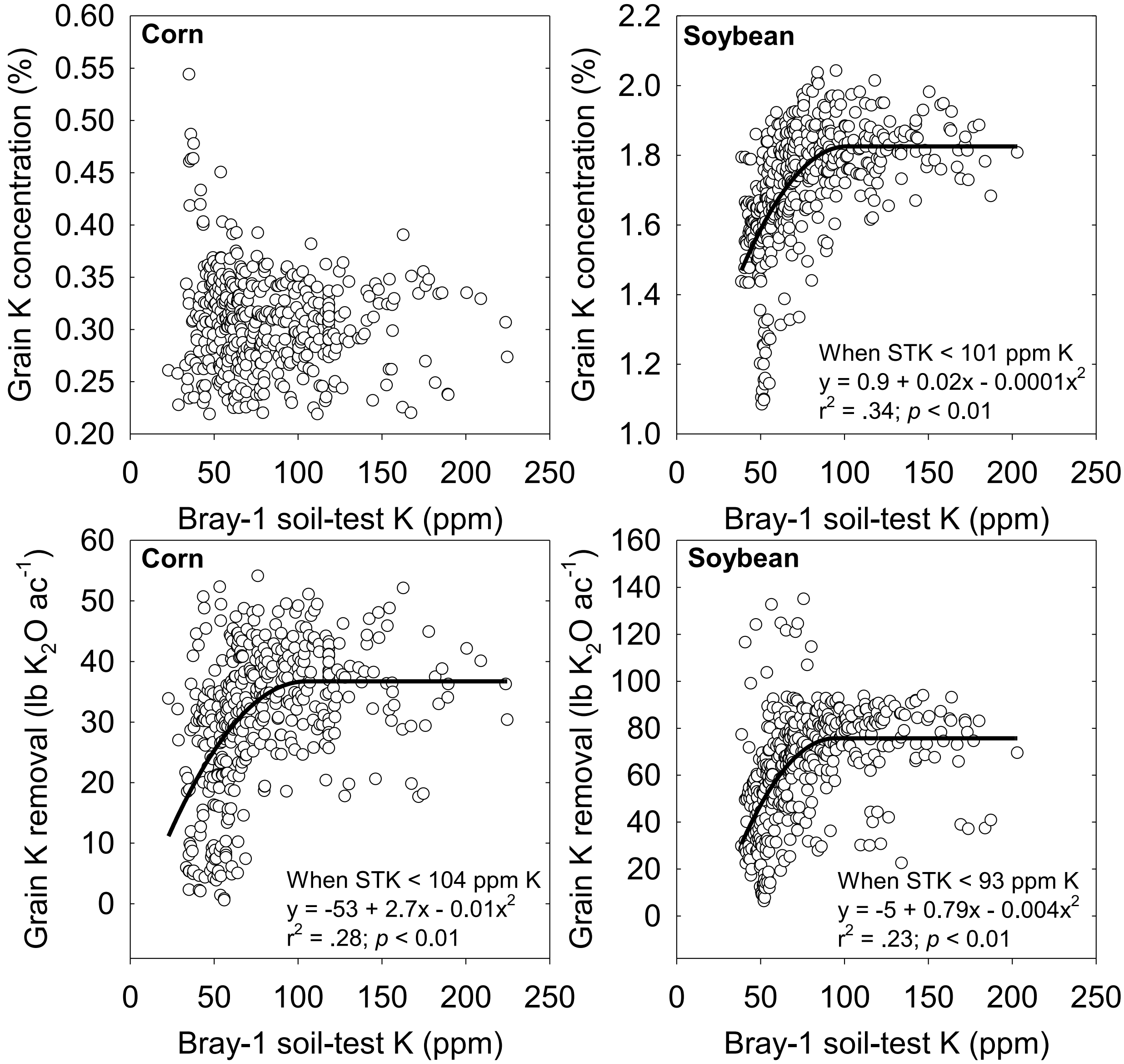

Figure 7. Relationships between Bray-1 soil-test K and grain K concentration and removal with harvest for corn and soybean.

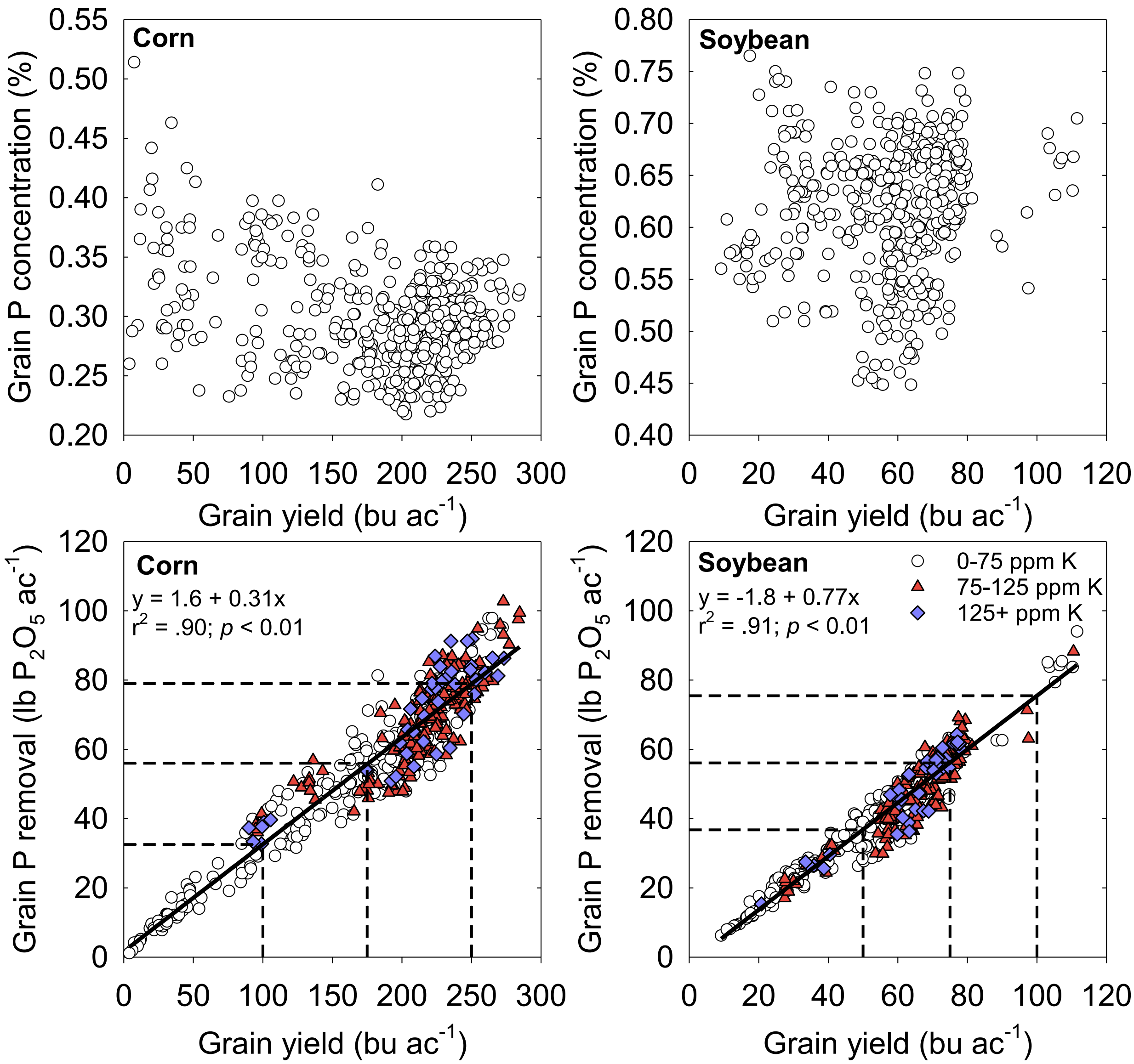

Figure 8. Relationship between corn and soybean grain yield and grain P concentration and removal with harvest.

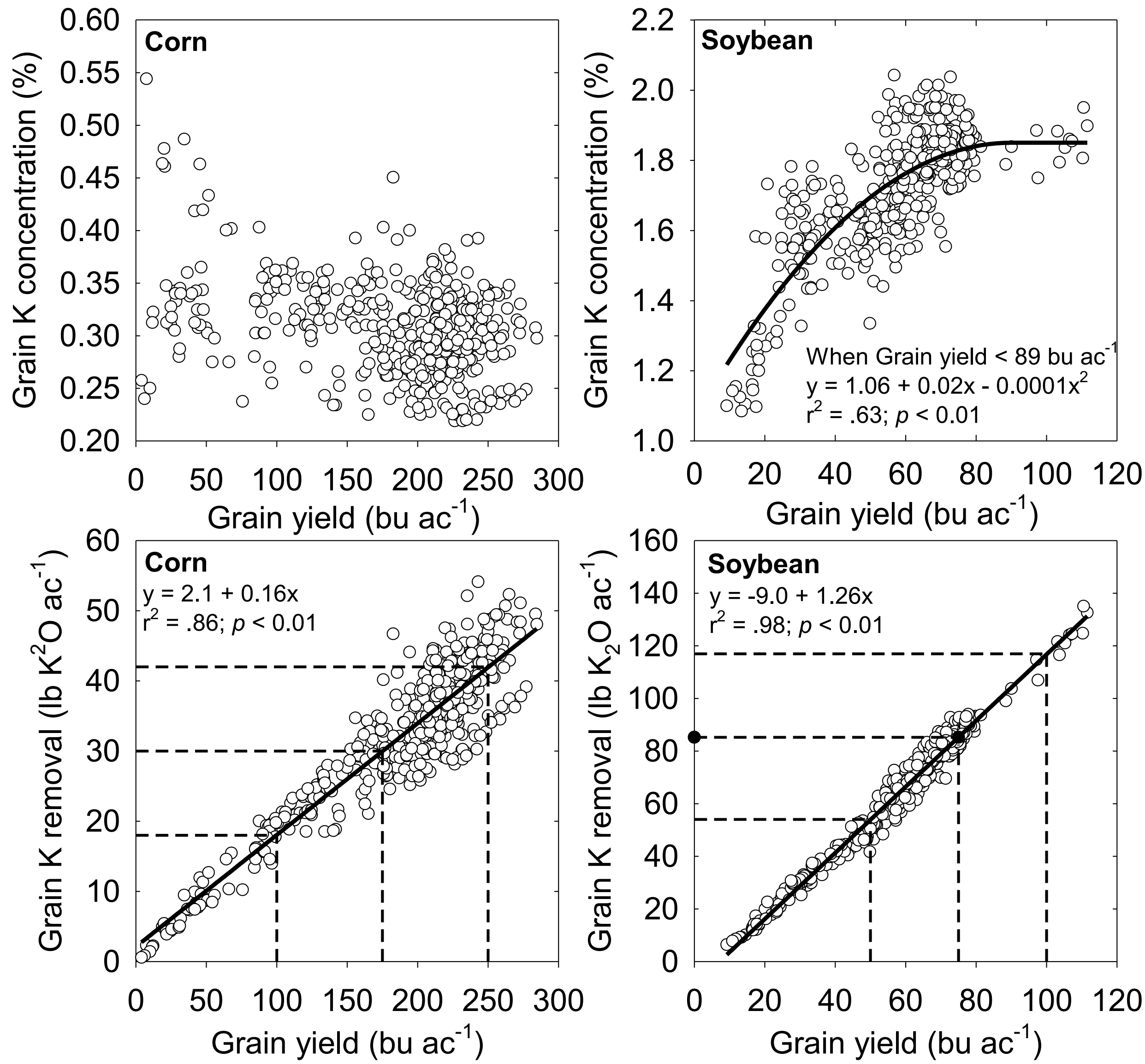

Figure 9. Relationship between corn and soybean grain yield and grain K concentration and removal with harvest