IOWA SOIL-TEST FIELD CALIBRATION RESEARCH UPDATE: POTASSIUM AND THE MEHLICH-3 ICP PHOSPHORUS TEST

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Iowa Phosphorus and Potassium Recommendations Until 2002

Iowa soil-test interpretations and fertilizer recommendations for phosphorus (P) and potassium (K) were last updated in 1999. The only change from previous recommendations (Voss et al., 1996; Voss and Mallarino, 1996) was to add interpretations for the Mehlich-3 (M3) P and K tests to existing interpretations for the Bray-1 P, Olsen P, and ammonium-acetate K tests (Voss et al., 1999). The interpretations for the ammonium-acetate and M3 K tests are similar because comparisons of amounts of K extracted from Iowa soils have shown no significant differences between these tests. The interpretations for the M3 P and Bray-1 tests (both based on a colorimetric determination of extracted P) are similar because comparisons of amounts of P extracted and field calibrations showed similar results in acid or neutral Iowa soils (Mallarino and Blackmer, 1992; Mallarino, 1997). However, the M3 test extracts more P than the Bray-1 test in many calcareous soils and it is better correlated with both the Olsen P test and crop yield response than the Bray-1 test across soils varying in soil pH. Other recommendations were not changed. Soil-test values are classified into two sets of interpretive categories for each nutrient (very low, low, optimum, high, and very high) that apply to soil series with low or high subsoil P and K levels. Less topsoil P and K are deemed necessary for crop production when subsoil nutrient levels are high. The probability of response within the optimum category (16-20 ppm P with the Bray-1 or M3 tests and 90-130 K ppm with the ammonium acetate or M3 tests) is considered small, and maintenance fertilization is recommended based on expected nutrient removal with harvest.

The fertilizer recommendations do not specify a tillage system or fertilizer application method. The recommendations are based mainly on research conducted using broadcast fertilization and the chisel-plow/disk system, which has predominated in Iowa during the last three decades. Iowa research from the 1950s to the 1970s (some of it unpublished) showed no major difference between band and broadcast placement methods for these tillage systems, and there was little or no local research with no-till or ridge-till systems. The recommendations specify, however, that starter fertilization for corn or sorghum could be advantageous within the high category under conditions of limited soil drainage, cool soil conditions, or with crop residues on the soil surface.

Soil-Test Interpretation Updates

Two major research developments during the late 1990s lead to one significant addition to the soil-test P interpretations and a significant change in soil-test K interpretations. Beginning in 2003, the soil-test P interpretations will also include interpretations for the M3 test extractant based on an ICP (inductively-coupled plasma) determination of the extracted P. Also, soil-test K interpretations for the ammonium-acetate and M3 K tests will change to recommend higher soil-test K levels. Other minor changes are not discussed here.

Interpretations for the M3-ICP Soil Phosphorus Test.

The M3 extractant was developed for routine testing of P, K, and other nutrients, and the determination of extracted P was based on a colorimetric method. The most commonly used determination procedure is based on the Murphy and Riley method. Research comparing the M3 test and other P tests (Beegle and Oravec, 1990; Mallarino and Blackmer, 1992; Mallarino, 1997) has shown that P measured with the M3 test is similar to or only slightly higher (1 to 2 ppm) than P measured with the Bray-1 test in acidic or neutral. However, the M3 test often measures more P than the Bray-1 test in high-pH, $CaCO_3$-affected soils (Sen Tran et al., 1990; Mallarino and Blackmer, 1992; Mallarino, 1997), which has been attributed to a significant buffer capacity of the M3 extracting solution. Iowa field calibrations (Mallarino and Blackmer, 1992; Mallarino, 1997) showed that the M3 test is more effective than the Bray-1 test and often is similar to the Olsen test for predicting crop response to P across Iowa soils ranging from approximately pH 5.2 to 8.2.

Adoption of ICP instruments by routine soil testing laboratories has expanded rapidly since the late 1980s (Munter, 1990). The ICP is displacing the colorimetric P determination used with the M3 test because its cost has decreased and several elements can be measured in the same extract. Because molecules injected into the plasma undergo instantaneous dissociation and ionization, ICP measures other P forms in addition to orthophosphate P. Thus, the P measured with ICP is usually higher than P measured with the colorimetric methods. Although research has suggested that the additional P is derived mainly from organic P compounds (Eckert and Watson, 1996; Eliason et al., 2001; Nathan et al., 2002), no consistent relationships have been found between the additional P measured with ICP and manure applications or soil organic matter (Nathan and Sun, 1998; Nathan et al., 2002; Mallarino, 2002). Most soil-test interpretations in the USA do not specify the M3 version used. However, in spring 2002, 66% of soil testing labs enrolled in the North American Proficiency Testing Program for the M3 test were using the M3-ICP version (Miller, 2002).

Field calibration research with corn and soybean conducted across about 80 site-years provide the basis for the first Iowa interpretations for the M3-ICP test. The average soil P measured by the M3-ICP, M3 colorimetric (M3-COL) tests across all sites of this data set was 31, 19, and 17 ppm, respectively. Fig. 1 shows relationships between P measured by the three tests. The R^2 of the relationship between the M3-ICP and M3-COL tests was 0.84 and did not change when high-pH sites (7.4 to 8.1) affected by $CaCO_3$ were excluded from the analyses. However, the relationship between the M3-COL and Bray-1 tests across all sites had an R^2 value of 0.89 and was improved to 0.97 by excluding a site with pH 8.1. Previous Iowa research also showed that the M3 extractant is better than the Bray-1 test for many high-pH soils (Mallarino, 1997).

Data in Fig. 2a show that the relative difference between the M3-ICP and M3-COL decreased exponentially with increasing soil P (M3-COL). However, there was no correlation between the absolute difference between the two tests and the soil P level (Fig. 2b). These relationships must be interpreted with caution because they may have been affected by other factors. For example, the additional P measured with the M3-ICP test decreased with increasing pH and organic matter (not shown), although the strength of the correlation was very weak (Mallarino, 2002). These results suggest that the additional P measured with the M3-ICP either is not extracted organic P or is organic P not directly related to organic matter measured by the soil test (organic C).

Figure 3 shows the relationships between the corn yield response to P fertilizer and soil-test P measured with the Bray-1 (colorimetric), M3-COL, and M3-ICP tests for samples collected from a 6-inch depth. Available relationships for soybean are not shown. When Bray-1 data for one highly calcareous site is excluded, the figures suggest no major differences in the capacity of the tests to estimate plant-available P. The research sites included chisel-plow/disk, no-till, and ridge-till management, but the tillage system had no consistent effect on the relationship between yield response and soil-test P. A shallower soil sampling depth for the no-till system increased soil-test P (as expected), but did not improve the prediction of yield response. In ridge-till fields, collecting samples only from the ridges (as opposed to both ridges and valleys) increased soil-test P and only slightly improved the prediction of yield response.

Several mathematical models (not shown) were fitted to data in Fig. 3 to calculate critical concentration ranges. In addition, additional economic and practical aspects were considered to establish soil-test interpretation categories for the M3-ICP test. The soil-test P interpretation categories for the Bray-1, Olsen, M3-COL, and M3-ICP tests in the new recommendations are shown in Table 1 (simplified from a table presented by Sawyer et al., 2002). Interpretations for the Olsen, Bray-1, and M3-COL tests are similar to those used since 1999.

New Interpretations for Soil-Test Potassium.

A need to update Iowa soil-test K interpretations was first suggested during the middle 1990s by an increasing frequency of K deficiency symptoms in corn, even in some soils that tested Optimum according to current soil-test K interpretations. Also, field experiments designed to evaluate K placement methods often showed larger than expected yield response in soils testing optimum, and small responses in soils testing within the High category. In the past, deficiency symptoms and large yield response were rare for the optimum category.

Field calibration trials have confirmed that use of current soil-test K interpretations sometimes would recommend too little or no K fertilizer for soils with a high probability of yield response (Fig. 4). The figure shows the relationship between relative corn yield and ammonium-acetate soil-test K, but results for the M3-K test were similar. The white data points represent data for soil series that do not deviate far from existing interpretations. The black points identify data for soil series in which the response to K was much larger than current interpretations would predict. Although all soil series represented by black points have low subsoil K, the white points include soil series with either low or high subsoil K in approximately similar proportions (not shown). Thus, the current sets of interpretation categories (two) based on subsoil K concentration could explain only partially the response differences.

Several reasons could explain both the increased soil-test K requirement for many soils and large response variation across soils with similar soil-test K. Ongoing research is addressing these issues and no firm conclusions are possible at this time. However, a very likely reason relates to a 1989 change from interpretations based on analyses of field-moist samples to dried samples. Ongoing research suggests that the average K extraction ratio between field-moist and dried samples used to adjust the previous field calibrations (which were based on field-moist analyses) was not appropriate for many conditions. As an example, data in Fig. 5 show the difference in extracted K for samples dried at different temperatures relative to a field-moist test (ammonium-acetate K). Differences in amounts of K extracted from air-dried or moist samples and the effect of drying samples at 40 or 50 °C vary markedly across sites with contrasting soil series and soil moisture content. These results confirm old research in showing that a uniform drying temperature across labs is critical to achieve comparable results. However, interpretations are complicated because previous and ongoing research suggest that the sample drying effects vary with the initial field moisture, the soil, and history of K fertilization. Preliminary data suggest that soil properties such as texture, clay mineralogy, or cation exchange capacity do not completely explain differences between analyses of moist or dried samples nor the differences in response. Moisture relations partly associated with internal soil drainage and landscape position also seem important.

The yield response data in Fig. 4 suggest two contrasting groups of soil series for which soil-test K interpretations should be different. However, because of the wide data spread below soil-test K values of about 170 ppm and a need to study responses for other conditions, the new interpretations apply across all Iowa soil series. Data in Table 2 show, as an example, the current and proposed interpretations and K fertilizer recommendations for corn and soybean grown in soils with low subsoil K. Ongoing research started this year that includes new field trials and additional soil analyses should provide information useful to develop specific interpretations for different Iowa soil series or regions in future updates.

Fertilizer Placement Methods Updates

With reduced tillage, broadcast fertilizers are not incorporated (such as in no-till) or are incorporated in a way that may not optimize early nutrient uptake (such as in ridge-till). Continued broadcast or planter-band fertilization and nutrient recycling with crop residues result in large P and K accumulation near the soil surface. Increased residue cover with conservation tillage improves water availability and root efficiency in shallow soil layers during dry periods but results in cooler and wetter soils in early spring, which may reduce crop growth and nutrient uptake. Thus, recommendations of fertilizer placement methods for conventional tillage may not apply to reduced tillage systems. These considerations and increased adoption of no-till management since the early 1990s prompted extensive placement research in Iowa.

Ten long-term studies assessed P and K placement methods for the corn-soybean rotation under chisel-plow/disk or no-till management from 1994 to 2001. Treatments were various rates of granulated fertilizers broadcast, deep banded, and banded with the planter. Approximately 80 additional short-term trials were established on farmers' fields managed with no-till and ridge-till systems. The planter-band treatment was not evaluated in these short-term trials. At fields managed with no-till or chisel-plow/disk tillage, the deep bands were applied at a 5-7 inch depth and at a spacing that coincided with the corn row spacing (usually 30 inches), and planter-applied bands were placed 2 inches beside and below the seeds. At the ridge-till fields, the deep bands were applied through a slit opened either through the center or the shoulder of the ridges and the fertilizer was placed approximately 3 inches below the planned seed depth. Summary results of these studies were published in this series (Mallarino and Borges, 1997; Mallarino et al., 2001) and in journal articles (Bordoli and Mallarino, 1998; Mallarino et al., 1999; Borges and

Mallarino, 2000, 2001). Thus, only a brief overview is provided here.

The research results were consistent in showing only small and inconsistent P placement differences for any crop or tillage system. These results confirmed results of Iowa research conducted decades ago. It is noteworthy, however, that no field tested less than 6 ppm in soil-test P (Bray-1) and that rates of 28 lb P_2O_5/acre or higher were evaluated. Thus, results and recommendations do not exclude the possibility of placement differences (mainly favoring the planter-band placement) when low fertilizer rates are applied to soils testing very low in P. Results of the K placement studies for crops managed with chisel-plow/disk tillage showed very small and inconsistent K placement differences. However, the results for no-till and ridge-till corn indicated that deep-band K applications often are more efficient than either broadcast or planter-band K (Figs 6 and 7). The differences were more consistent and larger for ridge-till corn than for no-till corn. Responses of soybean to K placement (not shown) were smaller and less consistent than for corn.

Based on these results, the new recommendations do not include specific guidelines for P fertilizer placement methods except for suggesting starter fertilizer under specific conditions as was done previously. In contrast to P, deep-band K fertilization is recommended for no-till and ridge-till management. However, it is stated that the no-till corn yield increase from deep K banding often is not large and may not offset increased application costs. Large variation in the no-till corn response to deep-band K seemed more related to soil moisture in late spring and early summer than to soil-test K stratification, and responses tended to be larger when rainfall was deficient.

Summary

Recent field calibration research with corn and soybeans provided the basis for an update of Iowa P and K recommendations. Results for the Olsen P, Bray-1, and M3 colorimetric P tests confirmed earlier soil-test P interpretations and no change was made. Increasing use of an ICP technique to measure P extracted by the M3 extractant and unpredictable differences with the standard colorimetric technique lead to field calibration research for the M3-ICP test. Early results of ongoing field calibrations for the ammonium acetate and M3 K tests based on dried soil samples showed large variation across soils and conditions, and suggested an urgency to increase the soil-test K levels considered optimum for crop production. Although the change was made uniformly across all Iowa soils at this time, ongoing research will likely provide useful information for establishing different soil-test K interpretations for different Iowa soil series or regions in the near future.

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Table 1. Updated Iowa soil-test P interpretation categories for four soil P tests and P fertilizer recommendations for corn and soybean.

Soil test	Soil-test category †				
	Very low	Low	Optimum	High	Very high
	ppm P				
Olsen	0-5	6-10	11-14	15-20	21+
Bray-1 or M3 colorimetric	0-8	9-15	16-20	21-30	31+
M3-ICP	0-15	16-25	26-35	36-45	46+
Crop	**Phosphorus fertilizer recommendation**				
	lb P_2O_5/acre				
Corn	100	75	55 ‡	0	0
Soybean	80	60	40 ‡	0	0

† Interpretations shown correspond to soil series with low subsoil P.
‡ The fertilizer amounts recommended for the Optimum category assume corn and soybean yields of 150 and 55 bu/acre.

Table 2. Current and updated Iowa soil-test K interpretation categories for the ammonium acetate and Mehlich-3 K tests and K fertilizer recommendations for corn and soybean.†

Soil-test category	Current recommendations			New recommendations		
		K fertilizer rate			K fertilizer rate	
	Soil-test K	Corn	Soybean	Soil-test K	Corn	Soybean
	--- ppm ---	---- lb K_2O/acre ----		--- ppm ---	----lb K_2O/acre ----	
Very Low	0-60	120	90	0-90	130	120
Low	61-90	90	75	91-130	90	90
Optimum ‡	91-130	40	65	131-170	45	75
High	131-170	0	0	171-200	0	0
Very High	171+	0	0	201+	0	0

† Interpretations shown correspond to soil series with low subsoil K.
‡ The fertilizer amounts recommended for the Optimum category assume corn and soybean yields of 150 and 55 bu/acre.

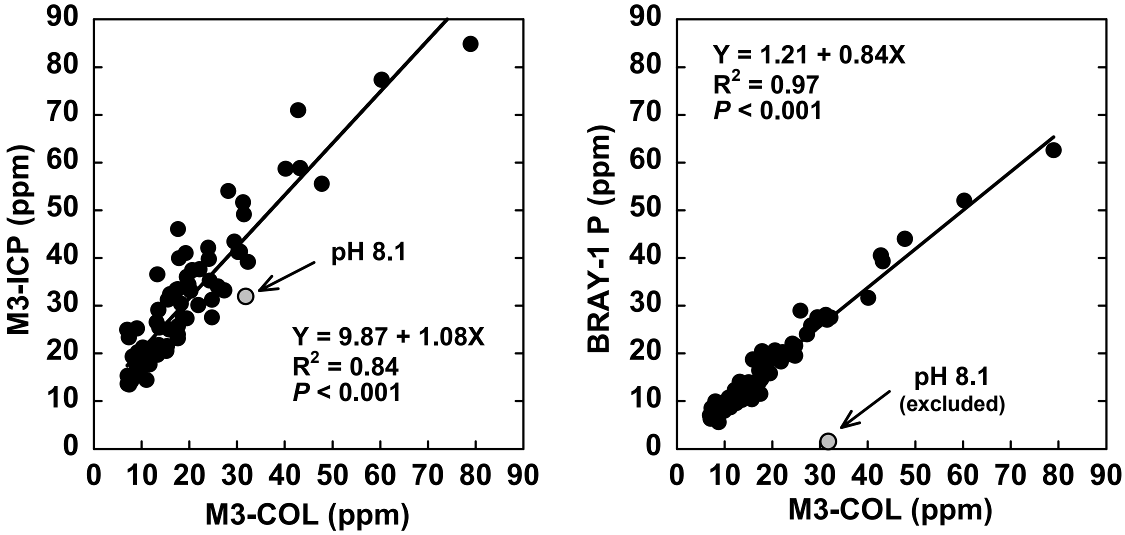

Fig. 1. Relationship between soil-test P measured with the Bray-1 test and the Mehlich-3 extractant with a colorimetric (M3-COL) or inductively-coupled plasma (M3-ICP) determination method.

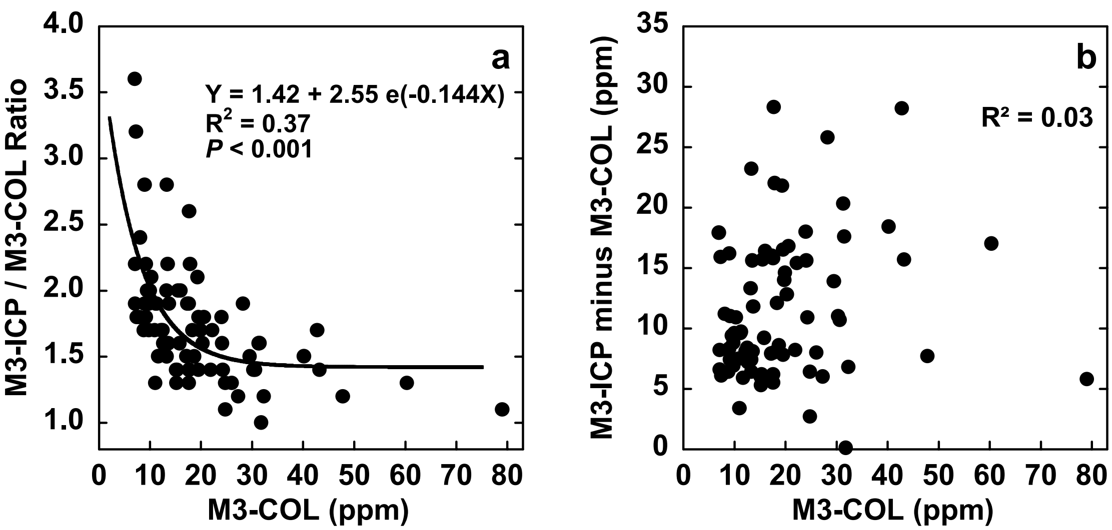

Fig. 2. Relationship between soil P measured with the Mehlich-3 colorimetric (M3-COL) test and the relative (a) or absolute (b) difference with soil P measured with the same extractant using an inductively-coupled plasma (M3-ICP) determination method.

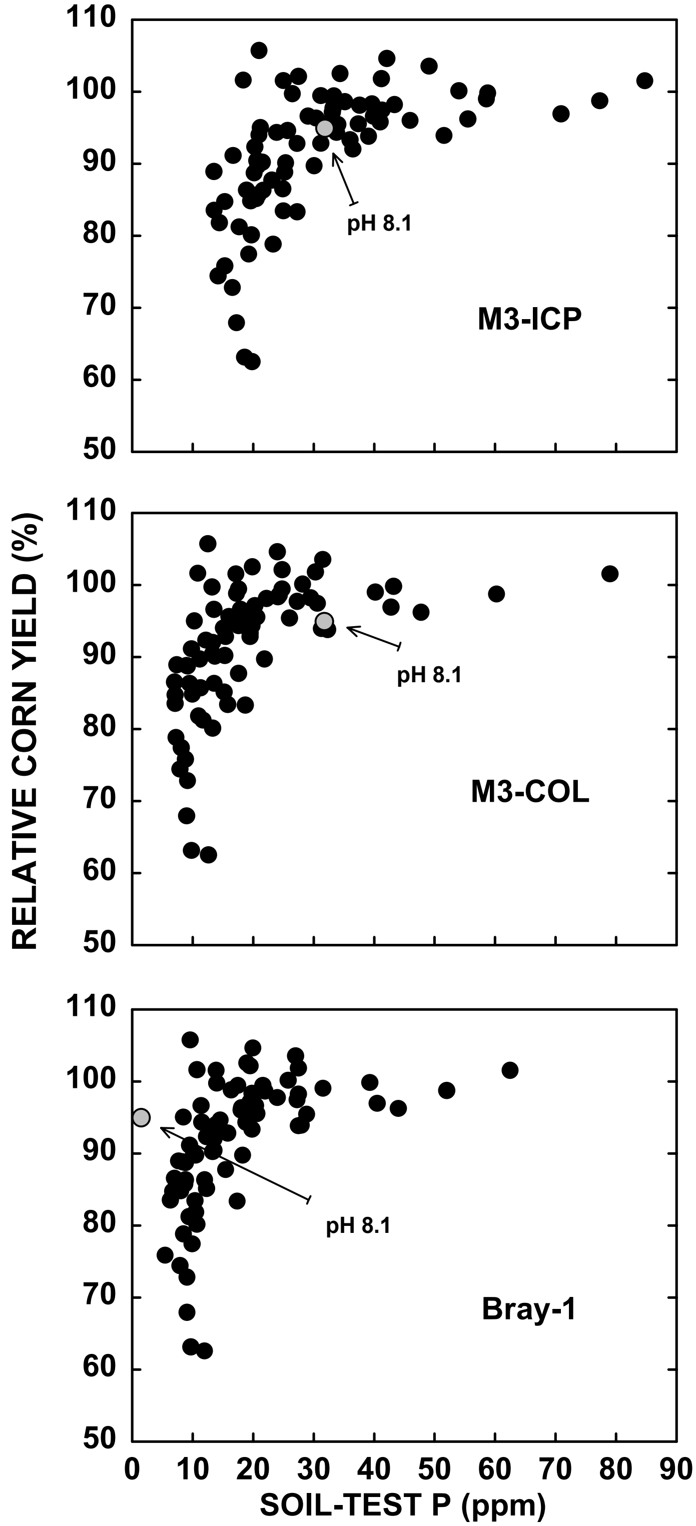

Fig. 3. Relationship between relative corn yield response to P fertilizer and soil-test P measured with the Bray-1 test and the Mehlich-3 extractant with a colorimetric (M3-COL) or inductively-coupled plasma (M3-ICP) determination method.

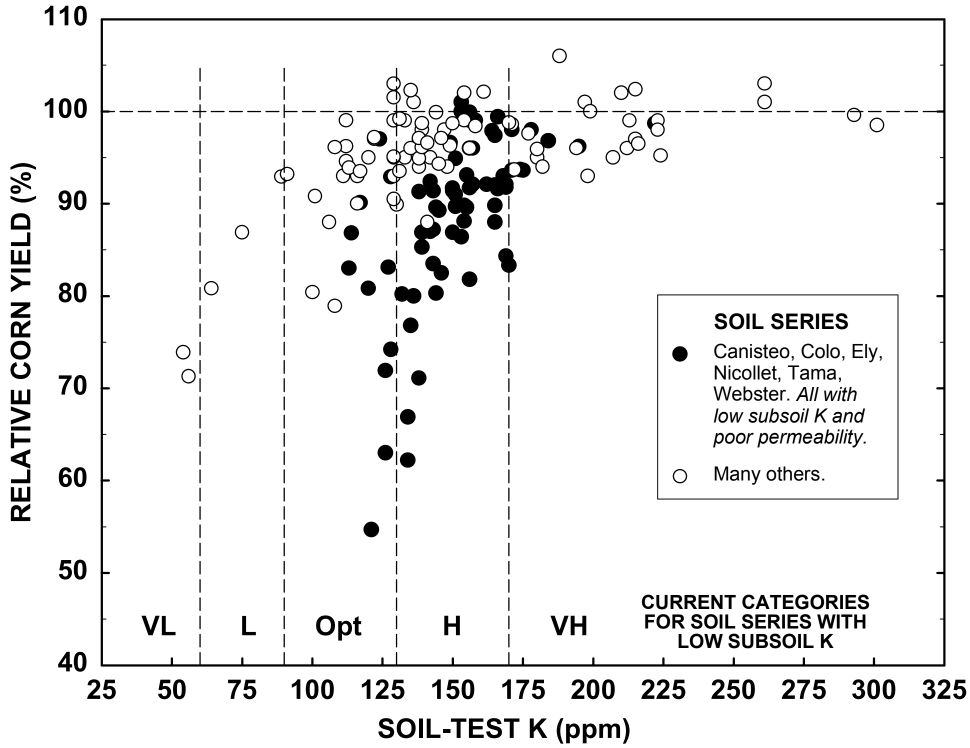

Fig. 4. Relationship between relative crop yield response to K fertilizer and amonium-acetate soil K (relationships and current soil-test interpretation categories for the Mehlich-3 K test were similar).

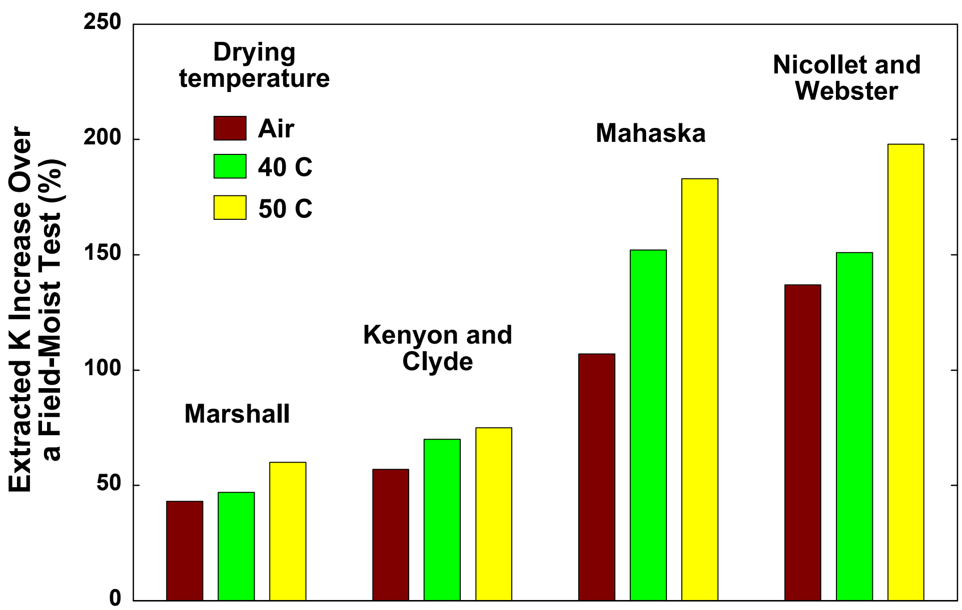

Fig. 5. Example of the effect of the sample drying temperature on soil K extracted with the ammonium-acetate test compared with a field-moist K test for sites with contrasting soil series.

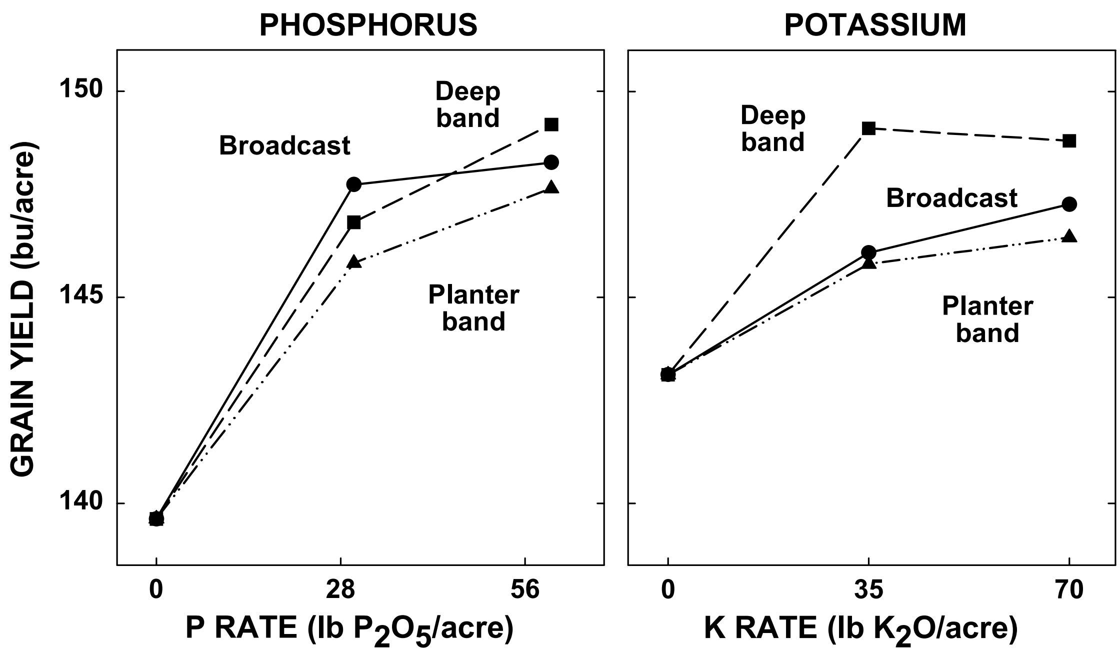

Fig. 6. Yield response of no-till corn to P and K fertilizer placement methods (means across 20 site-years).

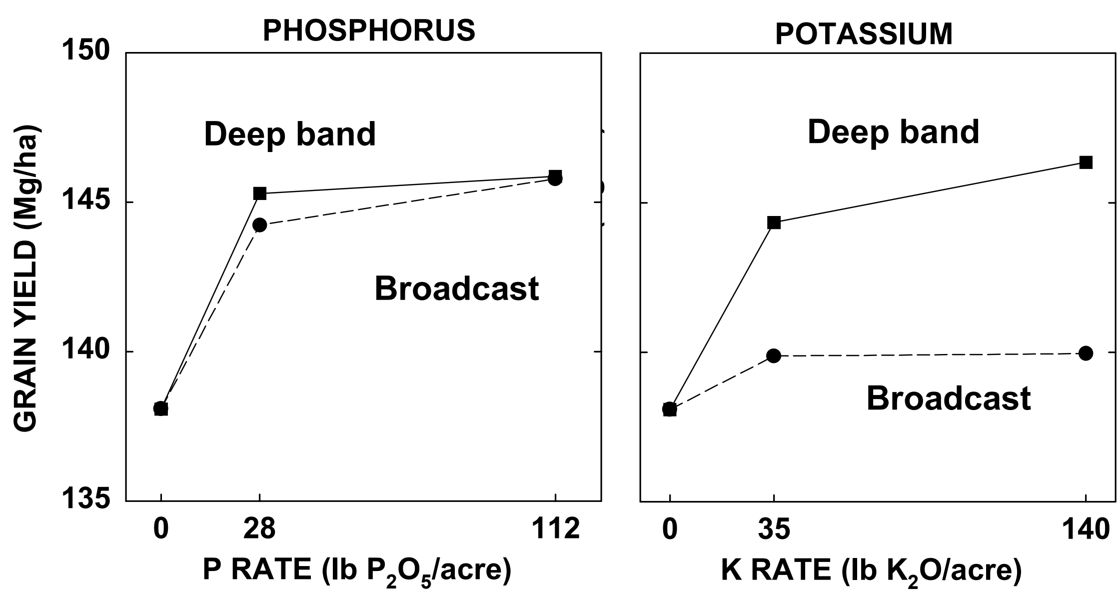

Fig. 7. Yield response of ridge-till corn to broadcast and deep-band P and K fertilizer placement methods (means across15 site-years for each nutrient).