Correlation of the Weak Organic Acids Test of a Soil Health Tool with Crop Yield Response to Phosphorus Fertilization

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ABSTRACT

The field correlation of a soil P test with yield response to P fertilization is the foundation for sound soil-test interpretations and fertilizer recommendation guidelines. Weak organic acid extractants have been used to measure soil P for decades in some northeastern states of the US and other countries, but not in Iowa or the Midwest. A new test based on a mixture of malic, oxalic, and citric acids (H3A) was developed as a component of a Soil Health Tool to measure soil P and K. The H3A test is used by several private laboratories operating in the Midwest as part of the Soil Health Tool. The H3A test has not been correlated with crop yield response to P or K fertilization in Iowa and many other states. This study correlated the P extracted by the H3A, Mehlich-3 (M3), Bray-1 (BP), and Olsen-P (OP) tests with corn and soybean grain yield response to P fertilization at 24 Iowa sites for a total of 54 site-years for corn and 58 for soybean. The sites encompassed several soil series with loam to silty clay loam texture, pH acid to neutral (6-inch depth) and were managed with no-till or chisel-plow/disk tillage. The P extracted by all methods was measured colorimetrically. Soil-test P ranges of plots used to assess yield response measured by BP, M3, OP, and H3A were 3-69, 3-74, 2-36, and 2-44ppm P, respectively. The H3A test was linearly and highly correlated with the three routine P tests (R^2 = 0.94 or 0.95), and on average the amount of P extracted was only slightly higher than for OP. Relationships between relative yield response and soil-test by each test were described by fitting quadratic-plateau (QP) and linear-plateau (LP) segmented polynomials models and an exponential model with decreasing increments to a maximum. All models fit significantly for all methods ($P \leq 0.001$), but the R^2 for the LP model were the lowest. The R^2 values of QP and exponential models were the lowest for the H3A test (0.33 to 0.40), intermediate for OP (0.50-0.54), and highest for BP and M3 (0.60-0.73). Critical concentrations ranges defined by the QP model and the exponential models using a 99% sufficiency levels for corn were 11-16, 14-20, 10-14, and 12-16 ppm for BP, M3, OP, and H3A tests, respectively, whereas critical concentrations for soybean were 11-14, 14-19, 9-12, and 14-19 ppm, respectively. The H3A test showed the lowest capacity to predict yield response when compared to the commonly used routine P tests. However, the identified critical concentration range for the H3A test can be used as the basis for interpretations pertaining to P sufficiency for corn and soybean in Iowa and similar soils.

INTRODUCTION

The concept of soil health is being widely discussed and referred to by researchers, conservationists, and crop consultants. Two conceptually different soil health assessment tools are being used in the US. One is the Cornell Comprehensive Assessment of Soil Health tool (CASH). This tool was developed for the Northeastern Unites States, although the concepts, framework, and measurements can be adapted for national and global applications. The other is the Soil Health Tool, commonly known as the Haney soil health tool, whose developers stated it has national applicability. The Haney soil health tool is the one being offered by several private laboratories operating the North Central Region and its results are being interpreted and used by a significant number of farmers, consultants, and organizations in the region. An adequate soil phosphorus (P) level for crop production should be part of a "healthy soil". The soil P level should be such that it is not deficient and or excessive. However, there is no general agreement concerning what defines a soil P level as excessive. Increasing soil-test P to much higher levels than needed to maximize yield could decrease crop yield but this seldom happens, may have undesirable effects on soil microbial population balance, and increases the risk of P loss from fields and water quality impairment. A key difference relating to P soil health assessment between the two mentioned soil-health tools is that the CASH tool uses existing calibrated and recommended soil-test P methods in the northeast region with interpretations transformed into a scoring system that is not crop or soil specific. In contrast, the Haney tool does not use commonly used soil-test P methods.

The extracting solution used by the Haney soil health tool to assess soil P (which is also used to measure potassium) is known as the "H3A test". The extraction is done with a mixture of diluted malic, oxalic, and citric acids (Haney et al., 2006; Haney et al., 2010). The common name is derived from the developers of the test (R. Haney, E. Haney, L. Hossner, and J. Arnold). The complete Haney tool is complex, and in addition includes the measurement of water-extractable forms of carbon (C), other nutrients, and CO_2 evolution to estimate microbial activity. The P extracted by the H3A test is measured colorimetrically and by inductivelycoupled plasma (ICP). As is the case for all soil-test P methods based on a chemical extraction, the measurement of extracted P with ICP often measures more P than the colorimetric method, which measures predominately orthophosphate dissolved P (Mallarino, 2003, Heckman et al., 2006; Adesanwo et al., 2013). The additional P extracted by the H3A solution measured by ICP is used in a complex way together with other measurements included in the tool to estimate mineralizable P.

Weak organic acids (acetic, citric, lactic, and others) have been evaluated to estimate crop-available soil P for a long time in some states and other countries. Therefore, the use of weak organic acids to extract soil nutrients is not new but specific organic acids, concentrations, and extraction procedures have changed over time. Early suggested extracting solutions and procedures (Dyer, 1894; Morgan, 1941) were modified or new extractants were developed since the 1940s to evaluate more appropriately crop-available soil P on the basis of field correlation research with crop response to P fertilization. These were mainly Bray-1 and Olsen tests appropriate for acidic or high-pH (calcareous) soils, Mehlich-1 for acid soils of the southeast, and Mehlich-3 for a variety of soils with different properties, which are the most commonly used test across the US. The Morgan test, which is based on acetic acid and sodium acetate (Morgan, 1941), and modifications (McIntosh, 1969; Jokela et al., 1998) is used in some northeast states. In other countries there have been numerous evaluations of tests based on diluted acetic acid, citric acid, lactic acid or mixtures of one or more of them, and are presently being used. Collaborative work conducted in soils of several northeast states of the US showed no clear differences between the assessment of crop-available P by the Morgan test and others such Bray-1, Mehlich-1, and Mehlich-3 (Heckman et al., 2006).

The H3A soil P measurement of the Haney tool has not be correlated with field crop yield response to P. Correlations of the amount of P extracted by the H3A test and commonly used P tests have been used as a preliminary way to learn how it may relate to P sufficiency for crops. It is well accepted by the scientific soil testing community, however, that correlations between amounts of nutrient extracted can result in inappropriate interpretations for a new soil test, and that correlations with crop yield response are essential (Fixen and Grove, 1990). The Bray-1 test, two versions of the Mehlich-3 test (colorimetric and ICP), and the Olsen P test have been correlated for Iowa soils with crop yield response and are the methods recommended to evaluate crop-available P since 2002 (Mallarino, 1997; Mallarino, 2003; Mallarino et al., 2013) and to be used in the Iowa P Index. Other P tests that have been suggested and seemed promising for assessing crop-availability of P or risk of P loss to water resources also have been evaluated in Iowa. These included two versions of “sink” type of tests that do not use a chemical solution to extract P and instead measure soil P based on ion exchange resins or iron-oxide impregnated paper (Klatt et al., 2003; Mallarino and Atia, 2005; Allen and Mallarino, 2006). These P tests have not been included in Iowa guidelines to measure crop-availability of P or the Iowa P Index because they are not better than the commonly used tests and are less practical or more expensive.

Therefore, this article summarizes ongoing Iowa research to correlate the P measured by the H3A test of the Haney soil health tool with corn and soybean yield response to P fertilization in several Iowa soils.

HIGHLIGHTS OF RESEARCH PROCEDURES

Conventional field-plot trials with corn and soybean were conducted at 24 Iowa sites with single-year or multi-year trials from 2013 to 2017. There were 54 site-years for corn and 58 for soybean. Data for additional trials are being summarized at this time. The trials encompassed seven soil series with loam to silty clay loam texture, soil pH (0-6 inches depth) ranging from acidic to slightly calcareous (pH 7.3 or lower), that were managed with no-till or chiselplow/ disk tillage. Each trial included several P fertilizer rates (0 to 112 lb P_2O_5/acre) replicated three to four times. Several trials evaluated broadcast and planter-band placement methods, but effects on crop yield did not differ for any tillage system. Soil samples were taken each year from 0-6 inch depth before planting the crops and applying the P fertilizer. Relative grain yield response was calculated for each trial by expressing the mean yield (across replication) without P fertilization as the percentage of the mean yield of P treatments that produced by the statistically maximum yield (the mean of all treatments, including the control, was used as maximum yield when there was no yield response).

The soil samples were analyzed by the Bray-1, Mehlich-3, and Olsen P tests following procedures suggested by the NCERA-13 north-central region soil testing committee using a colorimetric measurement of extracted P (Frank et al., 1998). The developers of the H3A test have made several modifications since was first proposed (Haney et al., of 2006), and soil samples were analyzed by Ward Laboratories using the last two of these modifications. Soil samples that were from 2013 through 2016 were analyzed by the so called H3A-3 procedure whereas samples collected in 2017 were analyzed by the H3A-4 procedure (Haney et al., 2017). The only difference between these two versions of the method is that the H3A-4 completely eliminated use of lithium citrate buffer which for the H3A-3 version had been significantly reduced compared with earlier versions. The elimination of the lithium citrate buffer in the H3A-4 version did not significantly affect the measured soil P concentration of numerous soils (Haney et al., 2017). The P extracted with the H3A test was measured colorimetrically and by ICP.

Regression analysis was used to compare the amounts of P extracted by the P test methods across all trials and additional soil samples collected from high-testing soils that were not included in the response trials. Relationships between relative yield response and soil-test values for each method were studied across the response trials. The relationship between relative yield and soil-test P by each method was studied and a range of critical concentrations for each method was determined by fitting the segmented polynomials linear-plateau (LP) and quadraticplateau (QP) models and an asymptotic exponential model with decreasing increments to a maximum the NLIN procedure of SAS. These models are frequently used to estimate critical concentrations or ranges for soil and tissue tests, and provide different estimates. The LP and QP models determine critical concentrations directly at a 100% sufficiency level (the concentration at which the two portions of the LP and QP models join). For the exponential model, we calculated critical concentrations for 95 and 99% of the maximum. The three models were statistically significant for all methods ($P \leq 0.001$) but the LP model showed the poorest fit and the critical concentrations determined by the QP model the exponential model for a 95% sufficiency level were approximately similar. Therefore, critical concentrations shown are those determined by the QP model and by exponential model for a 99% sufficiency level.

SUMMARY OF RESULTS

Figure 1 shows that the H3A, Bray-1, Mehlich-3, and Olsen soil P tests were linearly and highly correlated, with r^2 values ranging from 0.94 to 0.98. The soil P concentration measured by the Bray-1 and Mehlich-3 tests were approximately similar and the correlation between them was the highest observed (r^2 0.98), which was expected because no highly calcareous soils were included in the study. The Olsen P concentrations were approximately one-half the concentrations measured by the Bray-1 and Mehlich-3 tests, and the correlations with these two tests also were high and only slightly lower (r^2 0.95 or 0.96), which also was expected since no highly calcareous soils were included in the relationships. Previous Iowa research showed that the Bray-1 test underestimates crop-available P in many calcareous soils with pH higher than 7.3 and that the Mehlich-3 and Olsen tests correlate highly across all Iowa soils. The soil P concentrations measured by the H3A test were comparable to concentrations measured by the Olsen test. The correlations involving the H3A test were the highest with the Olsen test (r^2 0.97), and were only slightly lower with the Bray-1 and Mehlich-3 tests (r^2 0.94 and 0.95). The relationships between amounts of P measured by the four methods were similar for the five years with no obvious different linear trends for each year (not shown). As expected, measuring extracted P by the H3A test with ICP resulted in higher P values than measuring with the colorimetric method. Both measurements were linearly and highly correlated (r^2 0.96) and on average H3A soil-test P values were 11 ppm higher by ICP than with the colorimetric measurement (not shown).

Figure 2 shows the relationships between corn and soybean relative grain yield response to P with soil-test P measured by the Bray-1, Olsen, Mehlich-3, and H3A tests across all site years for each crop. Harvested grain yield ranges across all P treatments and site-years were 86 to 244 bu/acre for corn and 30 to 76 bu/acre for soybean. The relative yield increased (the response decreased) with increasing soil-test P measured by the four methods, but the relationships for some models and soil-test methods were better than for others. All models fit significantly for all methods ($P \leq 0.001$), but the R^2 for the LP model were the lowest. The R^2 values of QP and exponential models were the lowest for the H3A test (0.33 to 0.40), intermediate for OP (0.50. -0.54), and highest for BP and M3 (0.60-0.73). Critical concentrations ranges defined by the QP model and the exponential models using a 99% sufficiency levels for corn were 11-16, 14-20, 10-14, and 12-16 ppm for BP, M3, OP, and H3A tests, respectively, whereas critical concentrations for soybean were 11-14, 14-19, 9-12, and 14-19 ppm, respectively.

Therefore, the Bray-1 and Mehlich-3 tests showed the best relationships between soil-test P and crop yield response. The Olsen test did not predict crop yield response to the degree that the Bray-1 or Mehlich-3 tests did. The poorest relationship was for the H3A test, however. The observed relationships between crop yield response and soil P measured by the Bray-1, Mehlich-3, and Olsen tests are in agreement with relationships described by previous Iowa research. Both the degree of correlation and the soil P level needed to achieve maximum yield observed are approximately similar to results of previous research. The Olsen test is commonly recommended for soils with alkaline pH values due to elevated levels of calcium carbonate in the soil, which were not common in the sites included in this study.

CONCLUSIONS

The results should be considered preliminary because data from additional trials are being are being processed at this time that will be combined with the data that was presented. The H3A test showed the lowest capacity to predict yield response when compared to the commonly used routine P tests. However, the identified critical concentration range can be used as the basis for interpretations of the H3A test results pertaining to P sufficiency for corn and soybean in Iowa and similar soils.

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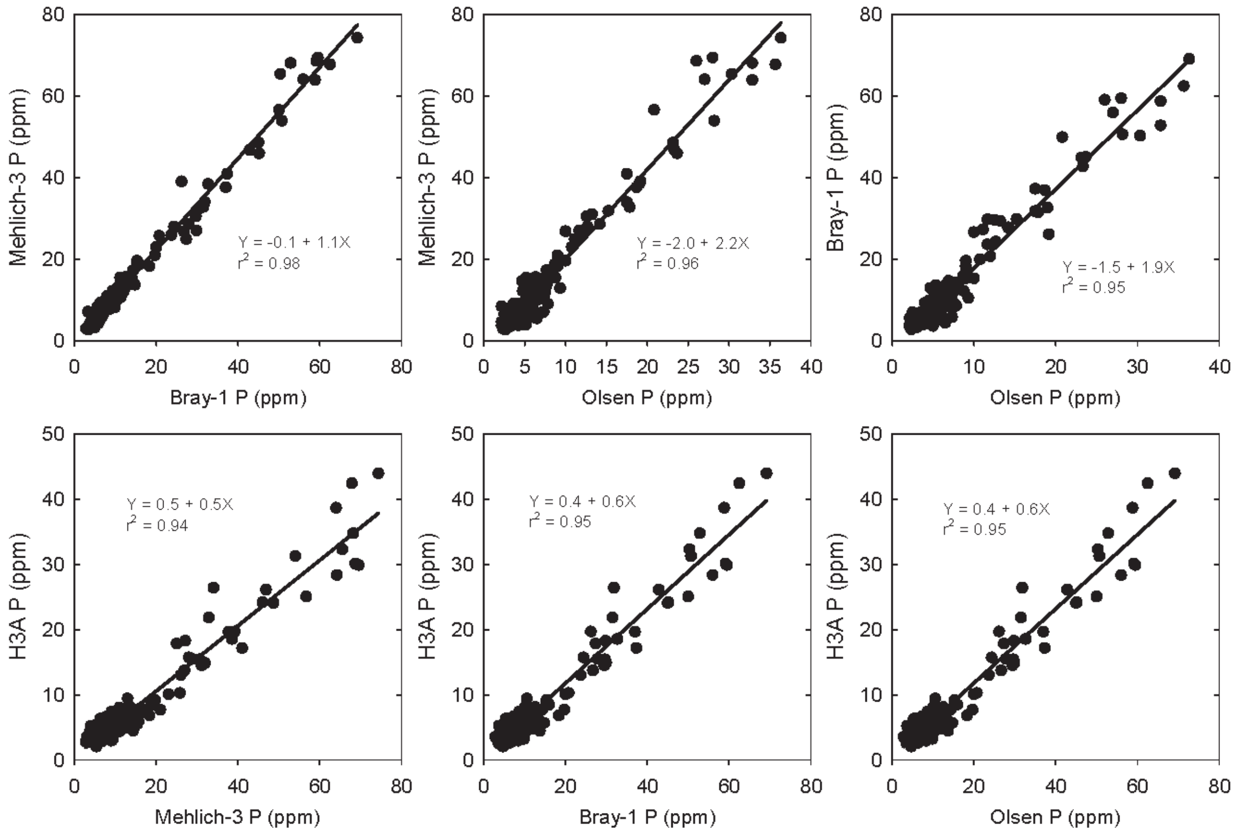

Figure 1. Correlations across all trials and years between amounts of soil P extracted by three routine soil-test P methods and the Haney soil health tool H3A method (means across replications).

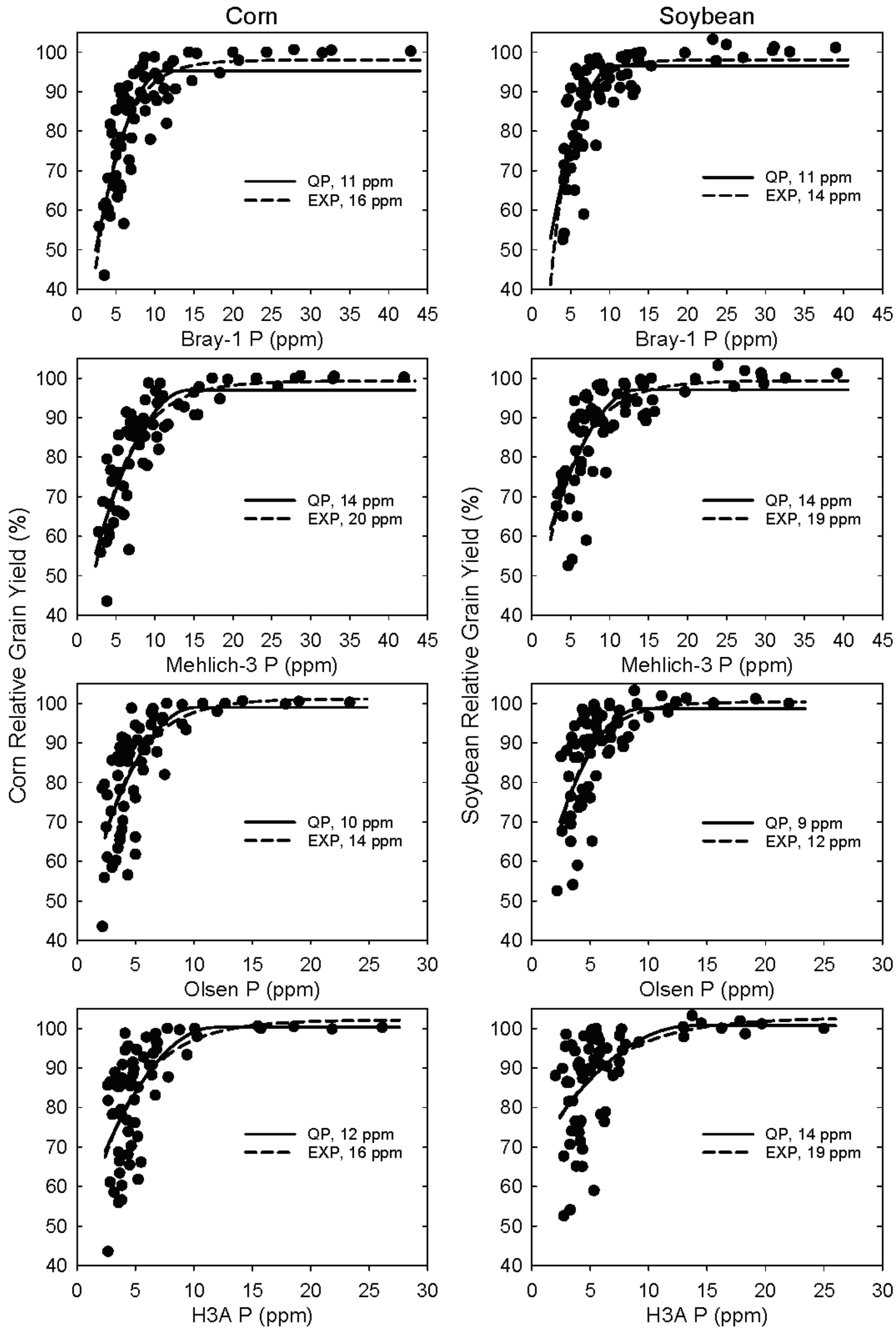

Figure 2. Relationships across all trials and years between relative corn and soybean yield response to P and soil-test P measured by four soil-test methods. QP, quadratic-plateau model fit and its estimated critical concentration; EXP, exponential asymptotic model fit and its estimated critical concentration estimated at 99% of the maximum.