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# Understanding Soil Tests for *Plant-Available* Phosphorus

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## Introduction

Phosphorus (P) is an essential element for all plants. Plants will grow slowly with low levels of P in the soil; however, for agricultural production purposes, the soil should provide a sufficient concentration of P for optimum plant growth. While this goal is easily stated, it is difficult to determine whether or not soil P is sufficient for optimum plant production. Consequently, much effort has been dedicated to the development of soil tests that determine the concentration of *plant-available* P, and whether or not that concentration is sufficient for optimum crop growth.

Soil testing has been practiced in one form or another for nearly 150 years. Modern soil testing was developed in the 1940s, and improvements in, and the use of, soil testing have increased in contemporary times. The soil P tests that are used today provide an indication of the level of soil P that is available to the plant. The tests do not determine the total concentration of P in the soil or even the actual concentration of available P, but provide an index measurement of the P that can be taken up by the plant. Many years of research are required to develop a valid soil P test. Soil P test methods for Ohio soils are described in the publication "Recommended Chemical Soil Test Procedures for the North Central Region" (1).

The purpose of this fact sheet is to discuss soil testing for *plant-available* P and the different soil tests used to determine soil test P. The majority of private laboratories in Ohio are using a soil test (Mehlich III) different from the one used to establish soil critical values (Bray-Kurtz P1). To ensure that historical recommendations are still valid an adjustment will be presented to determine Bray-Kurtz P1 values from Mehlich III measurements.

## Development of a Soil Phosphorus Test

**Correlation**—A useful soil P test requires that the testing be accomplished in a timely and accurate manner. Consequently, specific chemical solutions, known as extractants, are used to extract P from the soil. Development of the tests requires two phases of research—a correlation phase and a calibration phase. Since a determination of the *total* amount of P in the soil is not meaningful to a growing plant, a correlation between the amount of P extracted by the chemical extractant and the amount of P taken up by the plant in question is necessary. This quantity of P is known as the *plant-available* P, and the better the correlation, the better the test. In the development of soil P tests, correlations between P extracted and P uptake by the plant (for numerous extractants) have been evaluated. The extractant showing the highest correlation is usually the one selected for the test. Ideally, many different soils will have been used in determining the best extractant.

Figure 1 shows the correlation of the amount of P taken up by a test plant with the amount of P extracted from the soil by two chemical extractants.

In this example correlation, Extractant A shows a better correlation with plant uptake of P than does Extractant B. Consequently, Extractant A would be the extractant that would be chosen for the soil P test. Although this

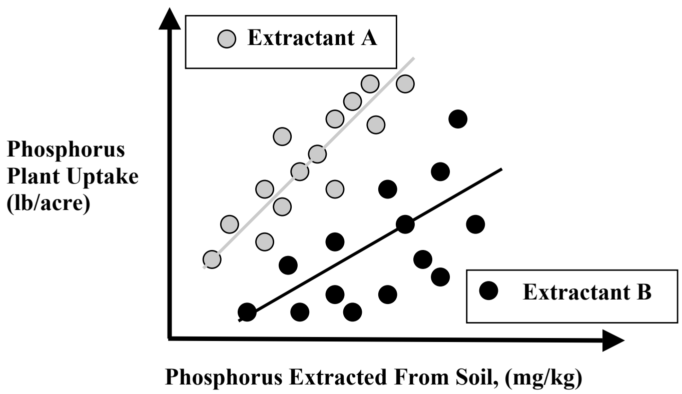


**Figure 1**. Correlation of two different extractions with plant P uptake.

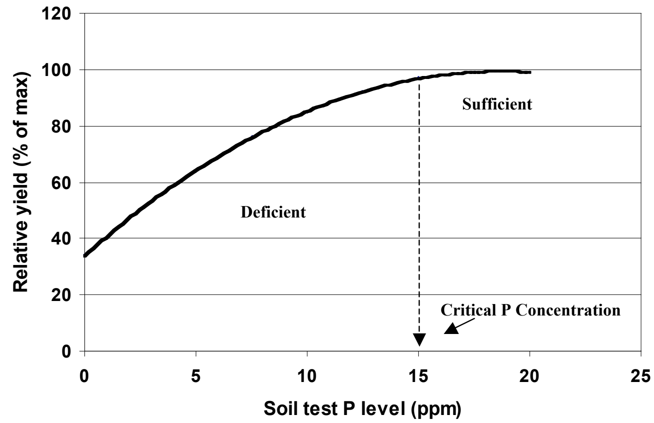


**Figure 2**. Relationship between soil test P level and relative yield. This correlation is used to identify the critical soil P concentration.

example shows only two extractants, in the development of the soil P test many different extractants would have been evaluated.

Once the extractant (chemical solution) has been selected, it is essential to relate soil test level to relative crop yield so that a critical level can be identified (the soil test level where P is no longer limiting). Thus, soils can be categorized as deficient or sufficient in plant-available P depending on how the crop response relates to the concentration of P in the soil test extract. To do this, soil test P level is correlated with relative crop yield (expressed as a percent of maximum yield) to determine the ability of the extractant to relate the nutrient concentration to crop productivity. The data in Figure 2 indicate that the critical level is 15 ppm for this particular crop and soil test. Generally speaking, the nutrient in question is not considered limiting if the relative yield is 95% of maximum yield. The relationship will also allow an estimation of crop response relative to soils very low in plant-available P to those soils that are high in plant-available P. For example, the data in Figure 2 reveals that a soil test level of 5 ppm P would result in 63% of the maximum yield if P were not limiting putting this level in the deficient category. Thus, if the soil is in the P deficient category, the calibration will provide information on how much increase in crop yield might be expected with increases in the concentration of plant-available P upon the addition of P to the soil.

**Calibration and Interpretation—**In order to determine the relationship among soil P test results, phosphorus fertilizer application rate, and plant response[1], research is carried out over many years and for many different soils for crops of interest. Recommended fertilizer P rates based on the soil tests can also be identified by conducting field work with a range of P fertilizer rates applied at various soil test levels. For example, Figures 3a and 3b show the fertilizer rate response to P at two different soil test levels (5 and 10 ppm respectively). This calibration would be repeated over as wide a range of soil test levels and conditions as possible. Thus, both the interpretation of the soil P test and the fertilizer P recommendation are established with the calibration. Notice that in Figure 3b (compared to Figure 3a) the response to fertilizer P is much less dramatic because the soil test level is closer to the established critical concentration.

## Recommended Soil Phosphorus Tests

**Bray-Kurtz P1 Test—**The Bray-Kurtz P1 test (often referred to as the Bray-P1 test) was developed in 1945 at the University of Illinois by Dr. Bray and Dr. Kurtz (2). The test's extractant is a dilute hydrochloric acid and ammonium fluoride solution. It is recommended for neutral and acid soils ($pH \leq 7.0$), but not for alkaline soils ($pH > 7.0$). The correlation between P uptake by the plant and the P concentration in the extractant ranges from 0.74 to 0.94 for soils of the North Central Region of the United States (3). The detection limit of this test is 1.0 part per million (dry soil basis) with a reproducibility of 10%. This test has

[1]This relationship is often termed the "calibration relationship."

been approved by the USDA's North Central Regional Soil Testing Research Committee for the acid/neutral soils of the North Central Region of the United States (1). Phosphorus fertilizer recommendations for crops grown on Ohio soils are based on this test.

**Mehlich-3 Test—**The Mehlich-3 test was developed by Adolph Mehlich in 1984 (4). It was a modification of previous Mehlich tests for the acid soils of North Carolina. The colorimetric version of the test has been approved by the USDA's North Central Regional Soil Testing Research Committee number 13 (NCR-13) for the acid/neutral soils of the North Central Region of the United States (1). It has not been approved by the NCR-13 committee for alkaline soils. The Mehlich-3 extracting solution consists of multiple chemical solutions: acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and the chelate, EDTA. The detection limit of this test is 1.0 part per million (dry soil basis) with a reproducibility of 10%. The correlation between the amount of P extracted and plant uptake of P ranges from 0.83 to 0.99 for North Central U.S. soils. With the development of Inductively Coupled Plasma Spectroscopy (ICP) instrumentation, it was found that not only the concentrations of plant-available P in the Mehlich-3 extracting solution could be determined, but also the concentration of plant-available potassium (K) and other nutrients could possibly be measured at the same time.

**Olsen Test—**The Olsen test (often referred to as the bicarbonate test) was developed for the alkaline soils of Colorado by Drs. Olsen, Cole, Watanabe, and Dean in 1954 (5). The extracting solution is a solution of weak sodium bicarbonate. The correlation between the amount of P extracted from the soil with the P taken up by the plant ranges from 0.73 to 0.96 for alkaline soil conditions (3). It is approved by the NCR-13 committee for alkaline soils (1).

## Comparison between the Bray-Kurtz P1 and Mehlich-3 Tests

Because of the economy and versatility of an ICP instrument, many soil testing laboratories have adopted the Mehlich-3 extractant for simultaneously determining the concentrations of plant-available soil P and K. However, Mallarino and others have shown that greater P concentrations are obtained from soils with the Mehlich-3-ICP method compared to the Bray-Kurtz P1-colorimeter method or the Mehlich-3-colorimeter method (6,7,8,9). Studies by Mallarino on Iowa soils showed that the Bray-Kurtz P1-colorimetric and the Mehlich-3-colorimetric soil P tests compared favorably in measuring plant-available P (6). The average P concentration of 59 Iowa soils was 17 parts per million (ppm) for the Bray-Kurtz P1 test and 19 ppm for the Mehlich-3 colorimetric test. However, Mallarino's work showed an average P concentration of 31 ppm with the Mehlich-3-ICP for the same soils. His studies showed that the absolute or relative differences between the Mehlich-3-ICP and the Bray-Kurtz P1-colorimeter methods were not highly correlated with the soil P level. Field calibration work on Iowa soils have shown that the Mehlich-3-ICP test has a similar capacity to the Mehlich-3 and Bray-Kurtz P1 colorimetric tests to predict

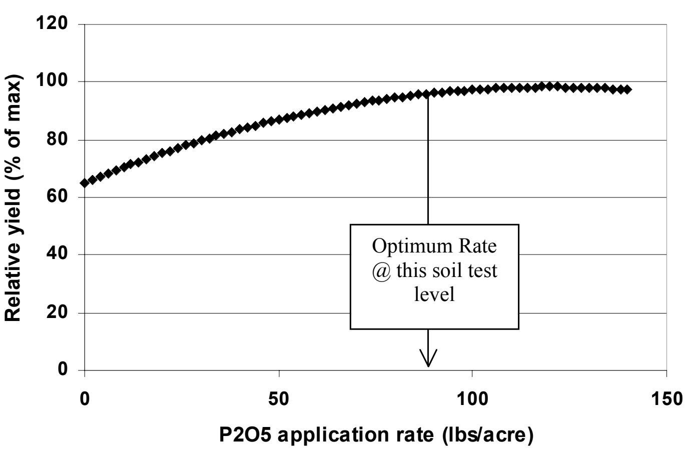


**Figure 3a.** Crop response (measured as relative yield) to applied P fertilizer for a soil with a soil test level of 5 ppm.

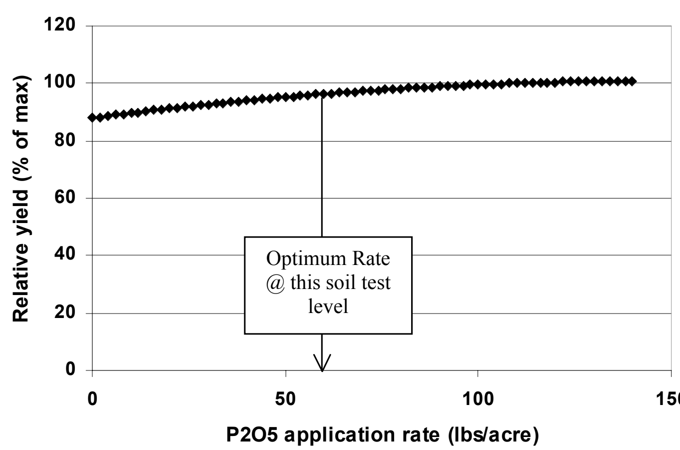


**Figure 3b.** Crop response (measured as relative yield) to applied P fertilizer for a soil with a soil test level of 10 ppm.

crop response to P. However, the critical P concentrations defined by Mehlich-3-ICP test was greater than that for the Mehlich-3 and Bray-Kurtz P1 colorimetric tests. In Mallarino's study the critical P concentration ranged from 20 to 32 ppm for the Mehlich 3-ICP compared to 16 to 21 ppm for the Mehlich-3 colorimetric test and 13 to 20 ppm for the Bray-Kurtz P1 colorimetric test (6).

Because of high research expense, field calibration with the Mehlich-3-ICP method for Ohio soils has not been performed to date. Since the fertilizer recommendations for crops grown in Ohio soils are based on the Bray-Kurtz P1-colorimetric method and many soil testing laboratories are using the Mehlich-3-ICP method, the question is how can Mehlich-3-ICP test results be used for making P fertilizer recommendations for Ohio soils?

Laboratory research was conducted by Eckert and Watson to investigate the relationship between the Mehlich-3-ICP and the Bray-Kurtz P1-colorimetric methods on Crosby and Hoytville soils of Ohio (7). These soils are extensive and used mainly for corn and soybean production. The comparison of the data for the two methods revealed a linear correlation of 0.90 with the Mehlich-3-ICP P concentration being greater than that determined with the Bray-Kurtz P1-colorimetric method. The average P concentration of the combine Crosby and Hoytville soils was 30 ppm for the Mehlich-3-ICP method and 17 ppm for the Bray-Kurtz P1-colorimetric method. In order to utilize the P fertilization recommendations, which are based on the Bray-Kurtz P1-colorimetric method, the Mehlich-3-ICP values should be adjusted to Bray-Kurtz P1-colorimetric values as determined by the linear regression between the two methods.

The adjustment is:

**Bray-Kurtz P1-colorimetric value =**

**-8.08 + 0.832(Mehlich-3-ICP value)**

Work by Pittman, Zhang, and Schroder obtained a similar relationship for a comparison between Mehlich-3-ICP and Mehlich-3-colorimeter methods where a field calibration involving crop response for Oklahoma soils was unavailable (9).

Thus, in lieu of field calibration information, the adjustment equation is practical in order to make appropriate P fertilizer recommendations for Ohio soils.

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