Measuring Crop-Available Phosphorus

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Proper P management is important to minimize the risk of economic losses due to P deficiency or environmental degradation resulting from excessive P applications. The main image shows unfertilized soybean in the foreground of a P-deficient field. The inset image shows eutrophication due to excess P that was transferred to the water body.

Proper diagnosis of crop-available soil P is a critical first step to guide the use of P fertilizer in agriculture. Soil P tests provide an index of plant-available P, which is then used to determine the amount of supplemental P, if any, needed to prevent economic loss of crop value. Soil P tests also provide a means to monitor changes in available P over time, which is useful for making P management decisions that not only affect the crop, but also play a role in the protection of water quality (Fixen and Grove, 1990).

Within a growing season, plant tissue analysis can be used together with a soil test as a diagnostic tool to monitor the P nutrition of the crop. Plant analysis is said to be the "final judge of the success or failure of a fertility program" (Bryson and Mills, 2014). Research has shown that there is a consistent correlation between the P concentration in a specific part of the plant collected at a specific growth stage and the growth or yield of the plant. This relationship provides the basis for assessing P deficiency or sufficiency in the plant.

Testing soil to predict P availability generally consists of four steps: 1) collecting a representative sample; 2) analyzing the sample for plant-available P; 3) correlating the results of the analysis with known crop responses; and 4) calibrating and interpreting the results to make a fertilizer P recom-

SUMMARY

It is likely more critical than ever to have access to proven indicators of the plant availability of P given the awareness of the implications of its management in crop production and the surrounding environment. Methods of assessing P availability will vary regionally, but commonly achieve good correlation to plant response. Continued improvement in the delivery of P sources to crops is in turn encouraging research that is improving our understanding of how to assess the behavior of P in soil.

KEYWORDS:

plant-available P; labile P; soil testing; fertilizer recommendations

ABBREVIATIONS AND NOTES:

P = phosphorus

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mendation. Of the steps required for a soil P-testing program, the chemical analyses are usually the most accurate part. In this article, our main focus is soil analysis.

The chemistry of soil P is quite complex. Phosphorus in soil solution, the pool from which plant roots acquire P, is generally of low concentration and must be replenished by solid-phase P. This P is found in insoluble minerals, organic compounds, and chemical species that are not readily taken up by plants. A small fraction of the soil P is considered labile P, which is the solid-phase P that rapidly replenishes the solution P. The amount of labile P in a soil is one of several factors that determines plant-available soil P. Labile P and plant-available P are highly correlated, but not equivalent.

The amount of plant-available P is not a distinct value for a given soil. It varies with environmental conditions that affect both plant and soil processes. This presents a challenge for scientists who want to develop soil analysis methods that can quantify plant-available P. Fortunately, several useful P extraction procedures that correlate well with plant P uptake have been developed and continue to be refined.

The soil P analysis methods used by different laboratories tend to be quite empirical (i.e, based on past experience or observation). As the prevailing chemical species of P vary with soils, different methods that extract specific soil P fractions have been proposed for different situations.

The majority of soil samples are tested for available P by extraction with dilute solutions. More than a century ago, a 1% citric acid solution was used to extract P and other "available mineral plant food" from soils. Since that time, extracting solutions specifically targeting soil P availability have been developed. For example, the Bray P1 and Mehlich-1 methods are dilute acid extractants usually employed in more acidic soils, while the Olsen test (a bicarbonate solution) is more suitable for alkaline soils. Calcium lactate or calcium-acetate-lactate (CAL) extraction is popular in Europe, Australia, and elsewhere. The Mehlich-3 extractant was developed to be a multi-nutrient extractant that suits many soil testing laboratories due its cost effectiveness. Other tests, such as the ion-exchange resin and iron-oxide coated paper methods, work well with more diverse types of soils, but have not gained in popularity because of their perceived complexity. Ultimately, soil scientists should determine the most appropriate methods for each region or situation, based on local experimentation.

The results of plant-available soil P tests must be correlated with known crop responses (**Figure 1**) and calibrated in laboratory and field studies so that they can be interpreted and subsequently used to make P fertilizer recommendations. The better the correlation, the more accurate the soil P test.

Results of soil P tests are typically divided into classes, such as very low, low, medium, high, and very high. These

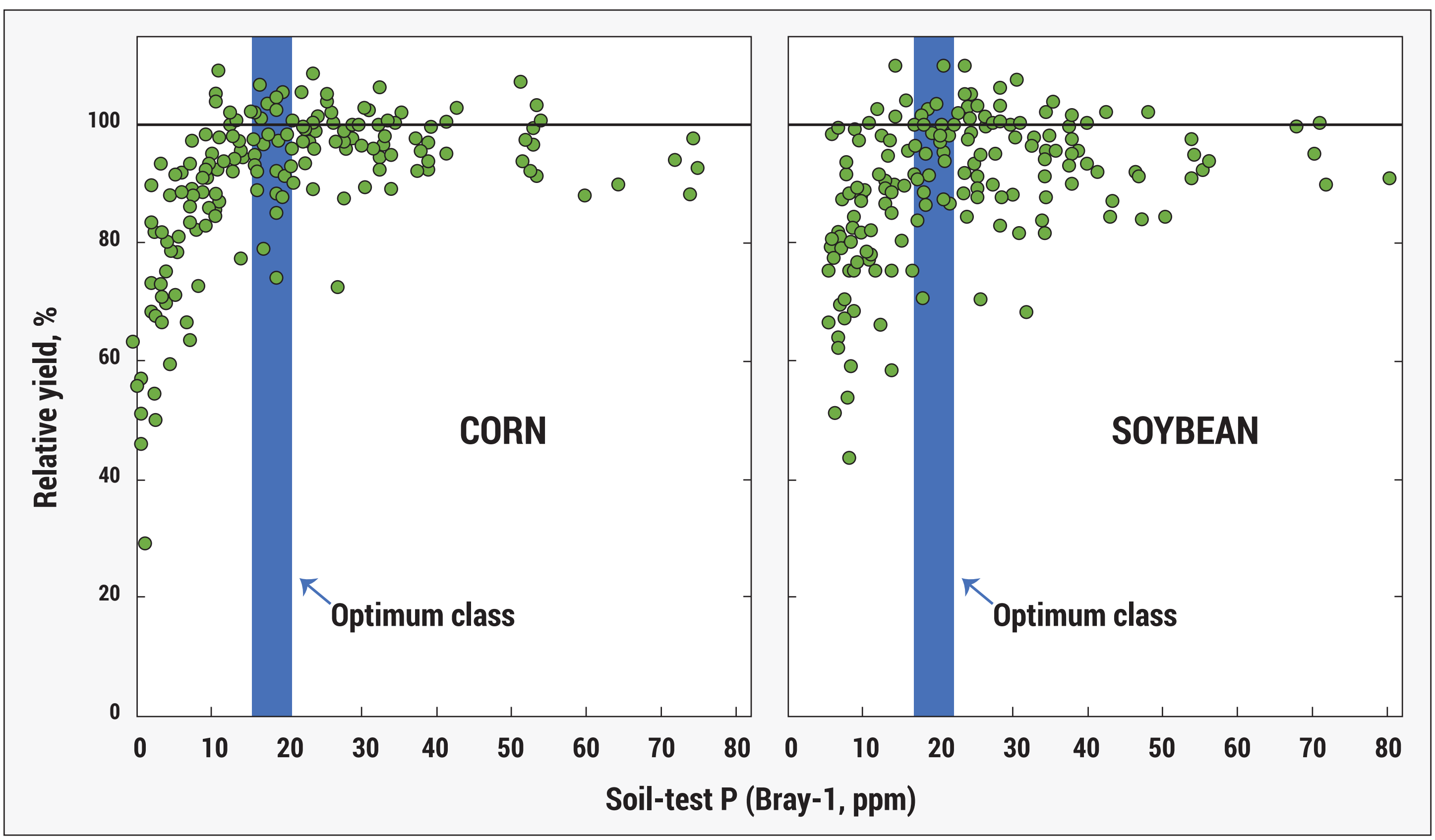

Figure 1. Relationship between soil-test P and relative yield of corn and soybean across several years of experiments at Iowa locations. Only maintenance P fertilizer is recommended if soil test P is in the optimum class (Modified from Mallarino, 1999). The blue bar indicates the range of P sufficiency.

TAKE IT TO THE FIELD

Soil analysis optimizes P fertilization for (1) crop yield and economic return, and (2) avoidance of unnecessary expenses and environmental risks in situations where additional P is not necessary.

There are different soil tests for P, but the interpretation of their results can be straightforward, and relatively simple: very low, low, medium, high and very high. End-users, such as farmers, consultants, and extension personnel, will intuitively know what the results mean.

classes are self-explanatory: soils testing low or very low require high inputs of P fertilizer to produce an optimum yield, whereas soils testing high or very high need little or no supplemental P. The amount of P fertilizer to apply also depends on the crop and the expected yields. Applying a fixed amount of P without determining available P with a soil test can result in crop yields below potential or unnecessary fertilizer application, negatively impacting the economic return.

Brazil has an interesting example of how selecting an adequate soil P method helped farmers to have a better diagnostic of available P. The prevailing soils in Brazil are oxisols that are highly acidic, P-fixing, and low in plant-available P. Yet acid extractant solutions containing hydrochloric and sulfuric acid may still underestimate plant-available P in many of these soils. This leads farmers to apply more P than necessary, especially in areas that have been previously fertilized.

Figure 2 (top) shows the relationship between relative yield of cotton and soil P as determined by an acid extractant versus ion-exchange resin in 27 fields. The acid extractant failed to differentiate between responsive and nonresponsive sites with soils having less than 10 mg P/dm^3, which theoretically should be low in P. When the ion-exchange resin method was used, it became clear that many of those soils that were classified as P deficient in the previous analysis had adequate available P, and the correlation between plant response and soil analysis was much better (**Figure 2**, bottom).

As can be expected, plant uptake provides a better indicator of available P in the soil. Much of the success of ion-exchange resin methods is based on the extracting procedure ability to mimic the action of roots capturing P from the soil solution (**Figure 3**). Based on this research and other studies, this method has been adopted by many laboratories.

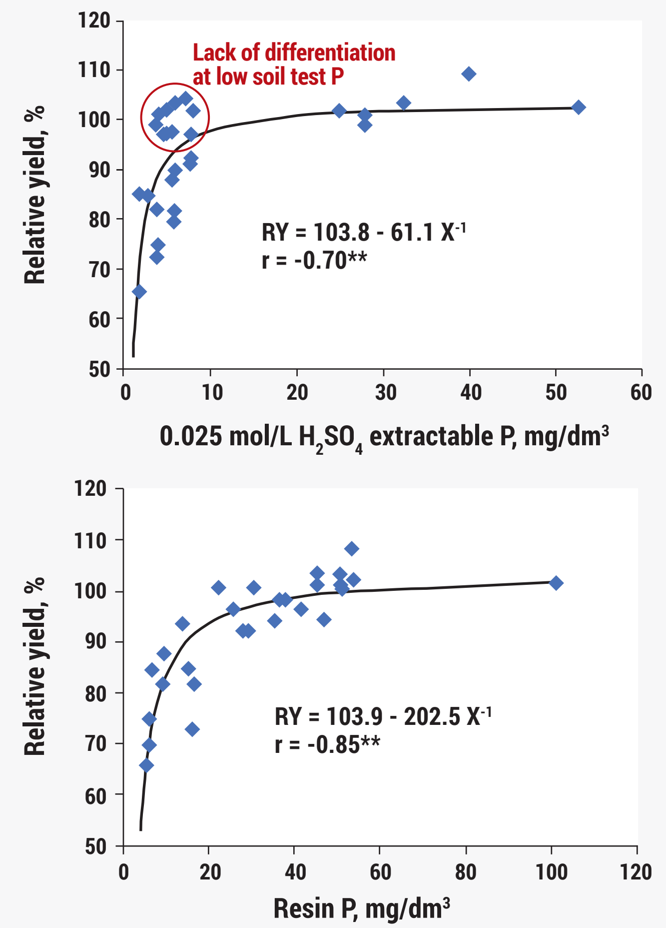

Figure 2. A nutrient extractant that matches soil characteristics is important for the determination of plant-available P. The acid extractant (top) performs poorly in acidic tropical soils, whereas ion-exchange resin extraction (bottom) provides a better diagnostic of available P for predicting relative yield (RY) (Modified from Raij et al., 1986).

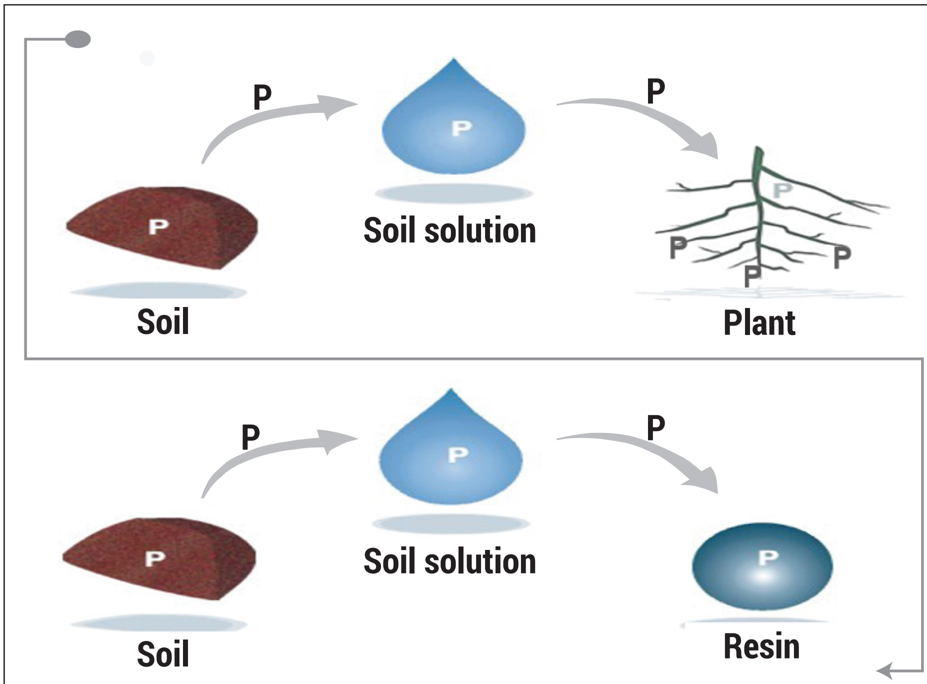

Figure 3. Schematic of P soil extraction with ion-exchange resin and how it mimics plant uptake of soil P (Raij et al., 2001).

Today, more than 100 soil testing laboratories in Brazil routinely use this procedure.

The sensitivity of the soil test to effectively detect low P is especially important in regions of the globe where P deficiency is common. In Brazil, approximately 80% of soils in the most important grain-producing region were originally P deficient. In regions where excess soil P may be a problem due to overfertilization or high manure inputs, soil testing is also an aid to manage crop nutrition and reduce environmental loss. In this situation, the choice of soil test method is less restrictive because most of them are able to indicate high concentrations of plant-available P. In any case, there is no good reason to avoid soil testing.

Closing Thoughts

The demands placed on soil P tests and their interpretations continue to increase. In recent years, we have acquired greater knowledge of the soil P cycle, soil P supply to roots, and the mechanisms of P uptake by plants, as well as the role P plays in our environment. Technological advances in fertilizer application (e.g., variable rate application equipment, applicator guidance systems) have surpassed the ability of most current soil P testing programs to provide recommendations. Therefore, research on improved soil P testing methods and more sophisticated interpretation of the results must continue. **BC**

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