

# **SOIL PHOSPHORUS TESTING FOR CROP PRODUCTION AND ENVIRONMENTAL PURPOSES**

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## **Introduction**

Increasing animal production in the state or its concentration in certain areas is increasing the amounts of manure being applied to the land. Often, the manure is applied at rates or at a frequency that exceed the phosphorus (P) needs of crops and even the amount removed in harvested products. Animal manure can supply the nitrogen (N) and P needed by crops as well as other nutrients. Due to its relative N and P content and potential N losses, however, continued use of rates that supply the N removed in corn grain (and in soybean grain too) results in P accumulation in soils. Accumulation in excess of crops needs may increase the potential for eutrophication of surface waters. Eutrophication means that nutrient levels in water, especially P, are high and excessive algae growth occurs, which could create imbalances in the water ecosystem and the esthetic value of water bodies such as lakes or streams. This problem is compounded because soils of many grain crop production areas already have soil-test P levels that are at or above levels that optimize grain yields. The upper limit for amounts of manure that could be applied with minimum environmental pollution could be ultimately determined by the P level in the topsoil and the potential for soil erosion, water runoff, or P leaching through the soil profile that can reach surface (through tile flow) or groundwater. This issue is calling for better estimates of P in soils, especially in manured soils, not only for crop production purposes but also for environmental resources conservation. Thus, questions have arisen concerning soil P testing for agronomic purposes or environmental purposes. A major question is the relative importance of a soil test value in terms of potential losses of P with erosion and runoff and if upper soil P limits can be reasonably determined to minimize P pollution of surface water supplies. A discussion of these alternatives necessitates a preliminary discussion of some basic aspects of P in soils, of the various types of tests, and their potential use for environmental purposes in comparison with routine soil tests for crop production.

## **Basic Aspects of P in Soils**

Most soils have a high capacity for retaining the P applied with chemical fertilizers or manure. Soluble P forms react quickly with the soil constituents and the P is adsorbed to fine mineral particles (clay, iron and aluminum oxides, carbonates, etc.), precipitates as inorganic compounds of low solubility (calcium and/or iron phosphates, for example), and can be tied-up in complex organic molecules. Thus, in most situations there is little movement of P through the soil profile and it accumulates near the soil surface when it is applied at rates that exceed crop removal. Losses of P through the soil profile are possible and important from an environmental perspective in some situations, however, because very small amounts of P are enough to stimulate algae growth.

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Significant movement of P has been described for situations involving coarse soil texture, very high fertilizer or manure application, and tilled fields with shallow water tables. In most situations, however, the most meaningful losses of P are to surface water supplies through soil erosion or water runoff, even when sometimes the tile water has high P due to runoff getting through tile inlets. Phosphorus may be lost from surface soils as sediment-bound P or dissolved P. Management practices that reduce soil erosion also reduce losses of sediment-bound P but may not affect, reduce, or increase losses of dissolved P. Dissolved P is immediately available for algae growth, although sediment-bound P also may result in eutrophication in the long term. Total P losses usually are larger for conventionally tilled fields than for no-till fields or pastures, although the proportion of dissolved P lost is higher for grazed pastures and no-till cropland. The capacity of the soil to retain P strongly influences the equilibrium between soluble, plant-available, adsorbed, and chemically bound soil P. This capacity varies among soils because of differences in mineralogy, chemical properties, and histories of P applications.

### Soil P Testing with Routine and Environmental Tests

Several routine soil P tests are commonly used to monitor P levels in soils for crop production. These tests measure a fraction of soil P assumed to be well correlated with P availability for crops and fertilizer recommendations are usually based on these tests. Research has produced field calibrations that are useful to determine critical concentration ranges and optimal fertilization rates for crops. The critical concentration range separates soils likely to respond to fertilization from soils unlikely to respond due to high soil P levels. Results of these calibrations for corn in Iowa are shown, as an example, in Fig. 1.

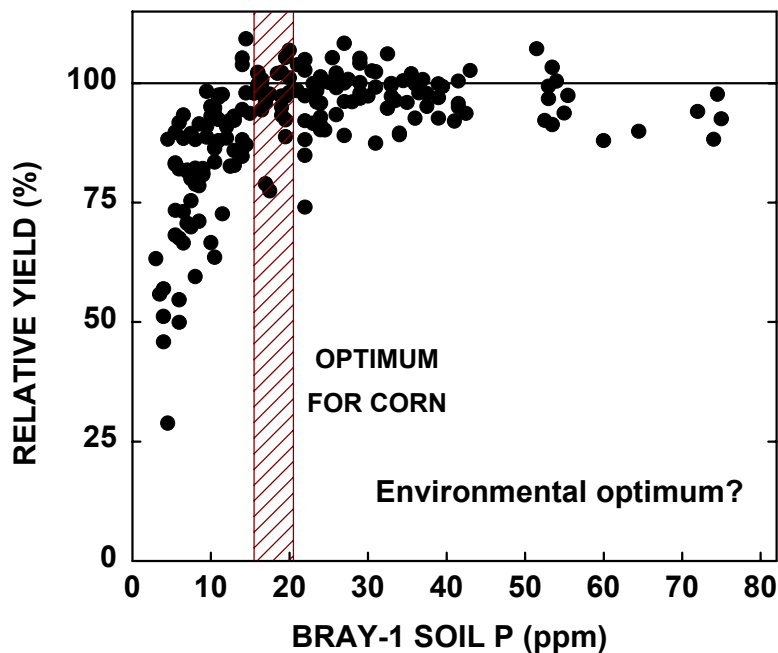


Fig. 1. Relationship between relative corn yield and soil test P for Iowa soils (only maintenance P fertilization is recommended for the optimum range).

The interpretations usually vary among regions and crops. Although these interpretations provide good information of the meaning of soil-test values from a crop production perspective, they may, or may not, be useful from an environmental perspective. It is uncertain how these tests and interpretations can be used as indices of the potential impact of soil P levels on degradation of water supplies. Routine soil tests that provide good estimates of plant-available P in soils receiving chemical fertilizers may not provide good estimates of excess plant-available P in soils receiving manures and may not assess bioavailable P in a broader sense. Forms of P well correlated with crop response to fertilization may not be good indices of forms that could degrade water supplies if they were transported with water runoff. Several P bioavailability tests have been proposed during the recent years to estimate P of soils and runoff water.

Studies are being conducted in Iowa to assess the availability of soil P for crops on fields receiving liquid swine manure and to correlate soil P extracted by routine tests with P extracted by bioavailable tests that could be used on a routine basis. Work also started this year to relate amounts of P extracted from the soil with P lost with runoff or tile water but results are not yet available at this time. Samples were analyzed for P by the Bray-P, Olsen (or sodium bicarbonate), and Mehlich-3 (M3) routine soil tests as recommended for soils of the North Central region. The P concentration in topsoil (0-6 inches) of the experimental plots and fields sampled ranged from values deemed deficient for crop production to values about ten times higher. Samples were also analyzed for bioavailable P using the iron oxide-impregnated paper strips, sodium hydroxide, anion-exchange resin membrane, and water extraction. Theoretical considerations suggest that these tests could be better related to P losses and to P that could be utilized by algae if soil or runoff reaches surface water bodies.

For this presentation, the results are summarized by focusing on two major aspects. One relates to relationships between amounts of P extracted by routine soil tests from manured and unmanured soils. The correlations between amounts of P extracted were always similar for unmanured or manured plots. The second aspect relates to relationships between soil P extracted by routine and bioavailability tests. Data in Table 1 show the correlation coefficients of relationships between amounts of P extracted by the three routine soil tests (Bray-1, Olsen, and M3) and the four bioavailable P (iron oxide, sodium hydroxide, and water) across all experimental plots and fields. The correlation coefficient can vary from zero to one, zero being no correlation at all and one being perfect correlation.

Table 1. Correlations among several P extractants across manured and unmanured soils.

Soil Test	Bray-1	Olsen	Mehlich-3	Iron oxide strip	Sodium hydroxide	Resin Membrane
----- Correlation coefficient -----						
Olsen	0.95					
Mehlich-3	0.97	0.97				
Iron oxide strip	0.93	0.93	0.93			
Sodium hydroxide	0.77	0.73	0.69	0.83		
Resin membrane	0.94	0.96	0.97	0.93	0.66	
Water	0.51	0.54	0.62	0.71	0.39	0.57

The correlations among the three routine soil tests were very high. The correlations with the Bray-1 test were even higher when data for a few highly calcareous soils were not included. The Bray-1 test extracted relatively less P than the other tests in these calcareous soils, which coincides with correlations of P extracted and field calibrations for corn for other Iowa soils. This problem with the Bray-1 test occurs mostly in soils of pH 7.4 or higher and calcium carbonate content greater than 5%. The data in the table also show the relationships between amounts of P extracted by the bioavailable and the routine soil tests. The iron oxide and resin tests were highly correlated but both tests were poorly correlated with the sodium hydroxide or water tests. The high correlation between the iron oxide strip and resin tests could be explained by comparable sink-based or exchange extraction mechanisms. Both tests were highly correlated with the routine soil tests. These high correlations were not expected due to the markedly different extraction mechanisms. Differences were expected for the sodium hydroxide and water tests, however, due to their markedly different P-extracting mechanisms. These two tests correlated poorly with all others tests.

Data in Fig. 2 shows, as an example, the effects of various manure treatments on soil P measured by the seven tests from plots of an experiment that received various rates of swine manure. The manure was applied shortly before planting corn, and soil samples were collected about five to six weeks after applying the manure. The sodium hydroxide test extracted the highest amount of P, which was two to three times the amount extracted by other tests. The Bray-1, M3, and resin tests extracted similar amounts of P. The P extracted by the Olsen test was lower, and it was followed in decreasing order by the iron oxide strip and water tests. The P extracted by all routine and bioavailability tests was linearly related to the amount of manure applied. Thus, each test evaluated manure effects on soil P in the same relative manner, although there were major differences between tests in the amount of P extracted.

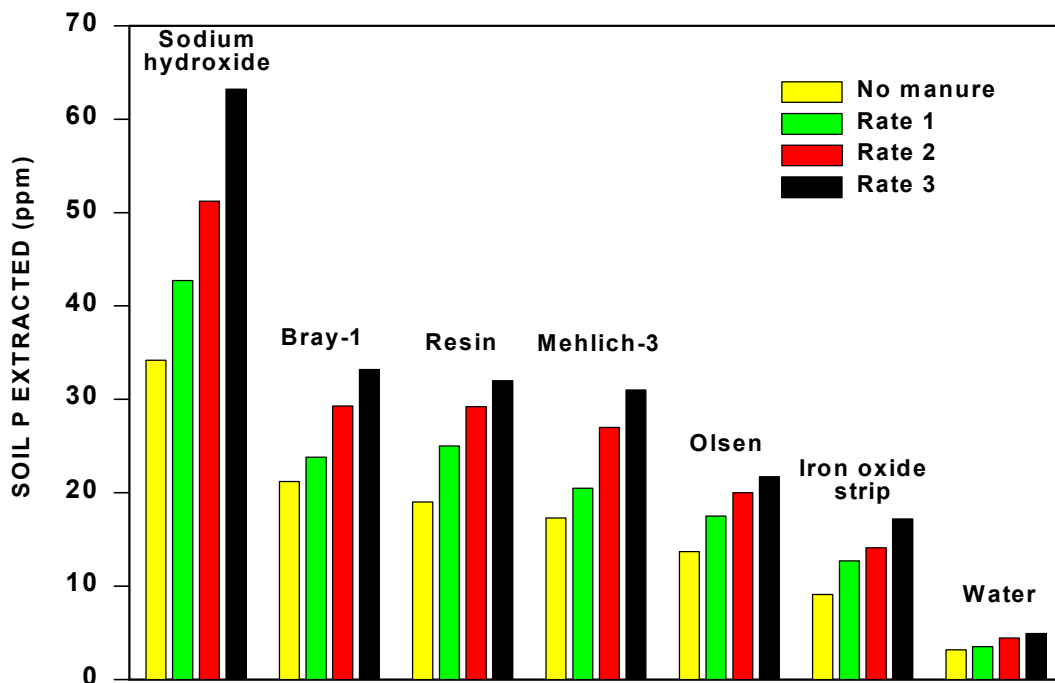


Fig. 2. Effect of three rates of swine manure on soil P extracted by three routine and four bioavailability tests.

## **Interpretation of Soil Test P Values for Environmental Purposes**

Differences in amounts of P extracted between tests are common, and is a well known aspect of soil testing. This is the reason why soil tests need to be calibrated with yield response to nutrient applications. A good soil test extracts a proportion of the P potentially available for plants and interpretations are derived from crop response trials. The value itself has little meaning in terms of the actual amount of nutrient in the soils (for example in lb/acre), it is just a value that should be proportional to what is available for a crop. The concept of calibration also applies when the main objective of soil testing is to estimate the amount of total or dissolved soil P that could potentially reach surface water supplies. This aspect can be addressed from two perspectives. One relates to the relationship between soil test P and potential loss of P and the other relates to the P that effectively reaches a water body away from the field. Concerning the first aspect, theoretical considerations suggest that soil P estimates based on sink-based tests (such as the iron oxide strip) or water extraction could be more useful because extraction mechanisms do not involve an arbitrary chemical method and they are better estimates of P saturation of the soil. When the soil is highly saturated in P its capacity to retain additional P decreases and the potential for losses of dissolved P increases. One important result of this study is the very poor correlations between the sodium hydroxide and water tests and between either of these and the other tests. Thus, it is possible that they have different type of relationship with P loss. The sodium hydroxide test has a strong extractant and measures much P that would be in the sediment fraction of runoff. The water extraction may correlate better with amounts lost in the dissolved P fraction of runoff or amounts that leach through the soil profile.

From the perspective of controlling P losses and setting upper soil P limits, the ideal situation would be that losses of P would increase significantly after a certain soil P value. This is the basis for suggesting of an upper limit for soil P. Although Iowa (or neighboring states) research is not available yet, research from other regions show linear relationships between soil P measured by either routine or bioavailable tests and dissolved or total P in runoff water. The data in Fig. 3 shows an example (for an Arkansas soil) of the relationship between dissolved P in runoff water and soil-test P measured by a routine soil test. It is possible that only when soil test levels are extremely high (some results suggest more than 15 or 20 times higher than levels considered optimum for crop production) the P loss may increase at a greater rate than the soil test P does because of higher saturation of the soil P-adsorption surfaces.

### **Soil P Testing and the P Risk Index**

The soil test P level has serious limitations as tools to predict P losses from soils. Obviously it cannot provide any good indication of the amount of runoff water or the P concentration in runoff that may occur for a specific situation. The amount of P lost from a field depends on the amount of water runoff and the amount of soil or dissolved P in the runoff. Moreover, the most relevant measurement is not the amount of P in the runoff that can be collected at the border of the field but the amount effectively transported to a nearby stream or water body. Thus, factors influencing soil erosion and water runoff, the distance between the field and streams or water bodies, and any other factor affecting the transport of water or sediment are very important in addition to soil-test P. The problem is compounded by consideration of the depth from which the soil sample should be collected, the depth that is relevant to predict losses of P and the method of manure or fertilizer application.

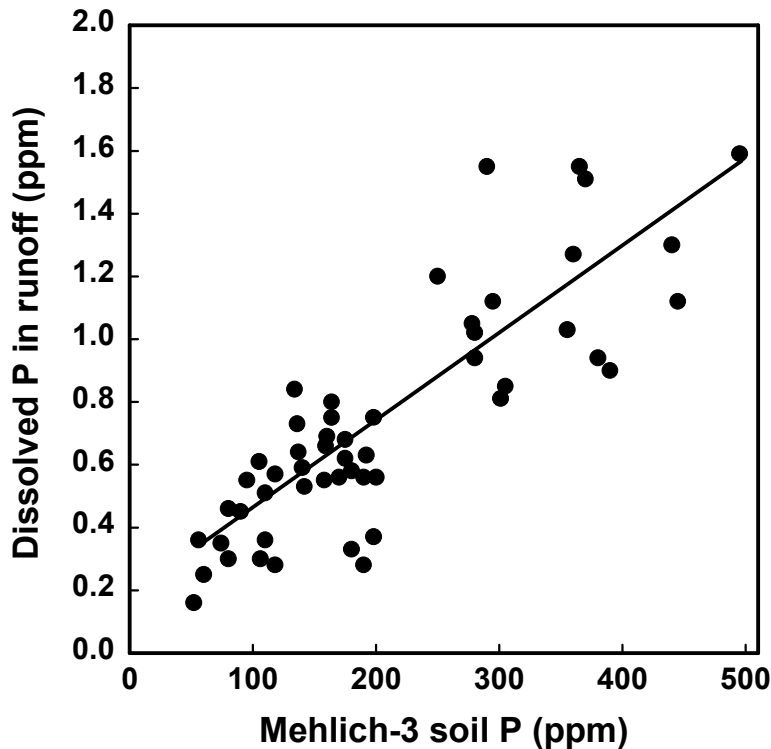


Fig. 3. Relationship between dissolved P in runoff water and the soil-test P level for a soil in Arkansas (from Pote and col., 1996).

For example, data in Fig. 4 shows the distribution of P with depth in a northeast Iowa soil that was managed for 20 years with four tillage systems and high rates of broadcast fertilization. The data shows that little P moved beyond the first foot of soil for any tillage, but P accumulated markedly within the top 3 inches of soil managed with ridge tillage or no tillage. The data show that the most appropriate sampling depth to estimate P losses with erosion or runoff likely is different for these tillage systems.

Thus, there is no one single, maximum level of soil-test P from an environmental perspective and other factors may be more important than the soil-test P level. However, soil test P is the easiest factor to measure, the easiest aspect to regulate, and usually receives more attention than all other factors. To account for this problem, P indexing procedure that could identify soils, land forms, and management practices with high potential for P contamination of water supplies should be developed. This indexing system integrates soil test P with many of the factors described above that affect P transport from the soil to water. A P index, as it is usually called, uses several characteristics to obtain an overall rating for a site. Each characteristic is assigned an interpretive rating with a corresponding numerical value for classes low to very high based on assumed relationships between the characteristic and the potential for P loss from a site. Ranges appropriate to each rating for a site characteristic are then assigned. In addition, a weighing factor is assigned to each of the characteristics in the P index to reflect its relative importance to P loss. For example, erosion and soil-test P are given more weight (about twice) than to P fertilizer application method. Because of lack of reliable research data, at present the weighting factors involve a great deal of subjective judgment. In addition, states usually modify (and should) the weighting factors as appropriate on the basis of local conditions. Because of

these considerations, a specific, maximum soil-test P level should not be set. However, upper limits ranging from 150 to 200 ppm (by the Bray-1 or M3 tests) have been suggested simply because they are higher (about five to ten times higher) than the P needed for crop production and seem low enough to minimize the concentration of P in runoff.

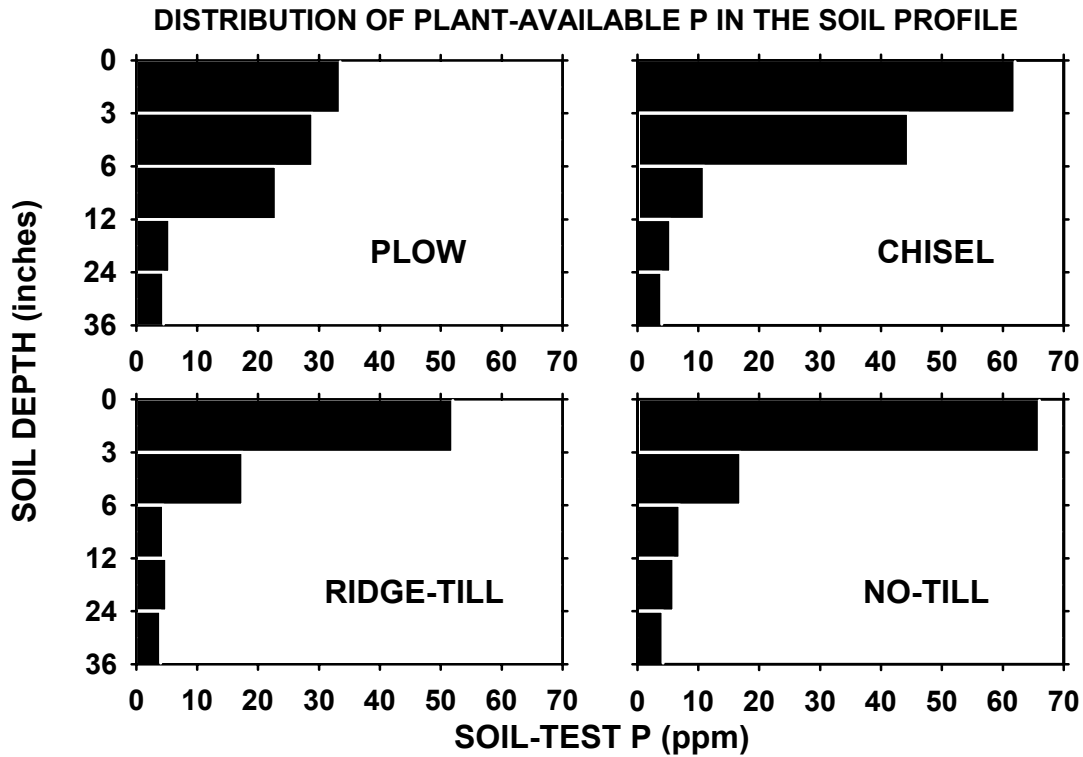


Fig. 4. Distribution of P with depth in a northeast Iowa soil that was managed for 20 years with four tillage systems.

### Concluding Remarks

Application of fertilizers or manure in excess of crop needs increases the risk of P losses to water supplies. Soil P extracted from unmanured or manured soils with commonly used routine soil P tests is highly correlated with P extracted by recently proposed bioavailable or environmental P tests. Research from other states is showing that soil P measured by routine soil tests is well correlated with dissolved P in runoff water at soil test levels as high as 10 to 15 times the optimum amount needed for crop production. Thus, routine soil-tests are good diagnostic tools to monitor P levels in manured soils for environmental purposes. The soil test P level, however, is only one of several important factors that determine the potential P losses to streams or water bodies, perhaps the least important. Soil sampling depth, soil properties, management practices, and landscape markedly influence the amount of sediment-bound or dissolved P that can effectively reach water bodies. Thus, no reasonable single upper limit of soil-test P can possibly be identified to protect surface water supplies. In addition, research shows that the amount of P in runoff increase linearly with the soil-test level. Thus, only

complex and currently unavailable research that ties soil test levels, all factors that influence P transport, and society defined acceptable eutrophication levels will provide needed answers. In the meantime, producers can minimize P pollution by recognizing that manure is a valuable source of P and other nutrients and that P rates that optimize crop production very unlikely cause environmental problems. Moreover, if it is necessary to apply rates that increase soil P levels above levels needed for crop production, producers can reduce P losses by understanding that some fields can accept higher manure loads than others.