The Importance of Sampling Depth when Testing Soils for their Potential to Supply Phosphorus to Surface Runoff

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Purpose of this publication

Soil-test phosphorus (P) results are an inherent part of agricultural nutrient management, both agronomically and environmentally (Thom and Sabbe, 1994). Historically, soil testing has been conducted for agronomic production, but is now being used as an environmental parameter to assess the risk of P transport in runoff. Interest in environmental soil sampling has been evolving since only the late 1980s and early 1990s (Sharpley and Menzel, 1987; Sims, 1993). While the relationship between soil P and runoff P has been well researched and discussed since then, a clear statement on the importance of sample depth in environmental soil testing for P has not been put forward. Agronomic soil samples are usually taken from 0-15 to 0-20 cm deep, where a large proportion of the active root zone is. Surface runoff in most cases interacts with only the top few cm of soil. Therefore, the issue of sampling depth is important when using soil-test P results for environmental purposes. This position paper presents the current scientific understanding of the effect of sampling depth during environmental soil P testing and recommends appropriate environmental soil sampling practices.

How Plants Get Their Phosphorus and Agronomic Soil Testing

Phosphorus is essential for crop growth and development. Crops obtain P entirely from the soil, but soils have a finite capacity to supply P. When that capacity is depleted, fertilizer P must be added to the soil to replenish it. Agronomic soil sampling and testing is designed to estimate the amount of soil P that is potentially available to plants over a growing season and to determine if and how much fertilizer is needed.

Phosphorus forms strong chemical bonds with soil, and is not nearly as mobile in the soil profile as other nutrients, like nitrate-nitrogen. With the exception of phenomena like rapid macropore flow in precipitation events that closely follow P applications, downward vertical movement of P is generally a slow, gradual process. In regularly fertilized soils, most P is thus in the topsoil, which is usually from 0-15 or 0-20 cm deep. There is typically much less P deeper in the soil profile. This pattern of vertical soil P distribution is routinely observed (Grant and Bailey, 1994; Guertal et al., 1991; Lucero et al., 1995; Malhi et al. 2003; Rechcigl et al., 1985) (Fig. 1). Plant roots extract the majority of their P from the topsoil because that is where the most soil P and greatest root density are. It is therefore recommended that agronomic soil samples intended to assess P availability to plants be taken from the top 15 to 20 cm of soils, although specific recommended depths may vary by crop and tillage practices.

How Tillage and Phosphorus Application Practices Affect Soil Phosphorus Distribution

In consistently and well-tilled soils, P is fairly uniformly distributed in the topsoil because tillage mixes soil and fertilizer P well (Andraski et al., 2003a) (Fig. 2a, b). The depth of uniform P distribution depends on the tillage implement used. For these soils, most guidelines recommend that agronomic samples be taken from 0-15 or 0-20 cm or the depth of tillage, but most often 0-15 cm.

For pasture, no-till, and even lightly-tilled systems, P fertilizers are not mixed as thoroughly into soils, and P is not evenly distributed throughout the topsoil (Crozier et al., 1999; Howard et al., 1999). Instead, there is often a distinct vertical P stratification, with most P in the top 5 to 7 cm and decreasing amounts of P with depth (Andraski et al., 2003a; Gaston et al., 2003) (Fig. 2c, d). In these soils, a soil sample taken to 15 or 20 deep will not show this P stratification, but will show an average P concentration throughout the depth sampled (Schroeder et al., 2004; Torbert et al., 2002) (Table 1). Because plants absorb P from the entire topsoil zone and because research sometimes shows no advantage of shallower sampling for predicting P fertilizer needs in these P stratified soils, many guidelines still recommend taking agronomic soil samples from 0-15 cm. However, a few guidelines recommend soil samples from shallower depths, such as 0-10 cm, to better estimate P availability to plants.

The P application method also influences soil P stratification. Besides broadcasting, P fertilizers and manures can be banded at a shallow depth with the planter, or banded (fertilizer) or injected (liquid manure) deeper into the soil. Shallow banding of P with the planter in tilled soils should distribute P uniformly throughout the topsoil because bands are seldom placed deeper than 5 to 7.5 cm and because tillage mixes the fertilizer well into topsoil. However, banding P fertilizers with the planter in no-till soils applies little or no fertilizer to the soil surface. This practice should result in more P concentrated in a 5-10 cm depth than in a 0-5 cm depth, but research has provided inconsistent evidence for such a pattern. This may be because of continued soil and band mixing over time or the inability of sampling depth methods to show patterns of P stratification (Eckert and Johnson, 1985; Tyler and Howard, 1991). Deep-banding P fertilizer or manure may concentrate P deeper than 10 cm.

The intensity or effectiveness of tillage will also affect the pattern of P distribution in tilled soils. Moldboard plows and heavy disk harrows will uniformly mix P fertilizer with topsoil, unless the fertilizer is placed below tillage depth. However, commonly used chisel plows, light disk harrows, or field cultivators may not uniformly mix P fertilizer into topsoils. Data in Fig. 3 from Mallarino and Borges (2005) illustrate vertical P stratification after banding P fertilizer from 12.5 to 17.5 cm deep during four years of no-till or chisel-plowing. Soil P concentrations were similar for both tillage systems across the 0-15 cm depth. Therefore, both tillage and P fertilizer placement method influence P distribution in the topsoil.

Using Soil-Test Data to Determine Phosphorus Available to Runoff

Transfer of P in surface runoff from agricultural soils has been implicated in the process of accelerated eutrophication of surface waters, which limits water quality for recreation, industry, or drinking (Carpenter et al., 1998). Concentrations of P in runoff, both dissolved in runoff water and attached to eroded sediment, increase as concentrations of soil P increase (Sharpley et al., 2001; Vadas et al., 2005). In an effort to minimize P transfer from soils to surface waters, it is critical to be able to identify those soils in the landscape that have the greatest potential to supply P to runoff. Therefore, the traditional practice of soil testing is now being used for this environmental purpose.

Studies have consistently shown that traditional agronomic soil samples taken for P fertility recommendations can also reliably assess a soil's potential to release P to runoff (Vadas et al., 2005). There are several reasons why it is attractive to use P results from agronomic soil samples to determine potential soil P transfer to runoff. Agronomic soil testing is a well-established practice that uses sound chemical and physical techniques to estimate soil P availability. There is already an infrastructure established to sample and analyze soils and to process and deliver results. There are historical databases available to determine regional trends in soil-test P results over years and decades. Using agronomic samples for environmental purposes also eliminates extra labor, cost, and education required to take and process separate environmental soil samples. Finally, soil-test P results will most likely be used in P indexes or models to assess the risk of P transport in runoff. Such P indexes often recognize that hydrology, changes in sediment loss, and potential P losses from unincorporated manure and fertilizer are as or more important in determining risk of runoff P loss than variability in soil-test P. Therefore, soil-test P results from agronomic samples may be adequate for intended uses.

However, there are some important differences in determining soil P that is available to plants and soil P that is available to runoff. As mentioned above, plants take P out of the entire topsoil zone. In most cases, surface runoff interacts with only the top few cm of soil (Ahuja et al., 1981; Sharpley, 1985), although this may not be true for situations of emerging flow on longer slope lengths (Sanchez and Boll, 2005). Soil P data used to estimate P available to runoff should thus accurately represent the P in the surface 5 cm of soil. For well-tilled soils where P is evenly distributed throughout the topsoil, the concentration of soil P from 0-5 cm will be about the same as the P concentration from 0-15 cm (Butler and Coale, 2005; Table 2). Therefore, an agronomic soil sample from 0-15 cm will likely give the same assessment of P available to runoff as a sample from 0-5 cm. In P stratified soils, P concentrations are greater from 0-5 cm than from 5-15 cm, and an agronomic soil sample from 0-15 cm or deeper usually shows less soil P than a shallower sample (Butler and Coale, 2005; Table 2). For example, if a soil has P in the top 5 cm of 150 ppm and P from 5-15 cm of 20 ppm, a soil sample taken from 0-15 cm might give a result around 70 ppm. From an environmental perspective, a soil-test P result of 70 ppm from a well-tilled soil is not the same as 70 ppm from a P stratified soil when similar 0-15 cm samples are taken in both soils. The P stratified soil is likely to have more P in the top 5 cm and greater concentrations of P in runoff (Vadas et al., 2005). Therefore, sampling depth is important when using soil-test P results for environmental purposes.

How Sampling Depth Affects the Relationship between Soil and Runoff Phosphorus

Studies have usually shown a linear relationship between concentrations of soil-test P and dissolved P in runoff. However, the slope of the linear relationship for P stratified soils can vary depending on the depth of soil sampling (Jacoby, 2005; Torbert et al., 2002). Data from Andraski et al. (2003b) in Fig. 4 and 5 illustrate this well. Their soil P data in Fig. 4 show that varying degrees of P stratification occurred in no-till and chisel-plowed soils at three different locations in Wisconsin that had similar tillage and fertilization treatments. Figure 5 shows that when soil-test P was related to dissolved P in runoff with data from 0-15 cm soil samples, the slope of the linear relationship was the same at the Arlington and Lancaster sites where there was little soil P stratification, but was much greater at the Fond du Lac site where soil P stratification was greater (Fig. 4). However, when soil-test P was related to runoff P with data from 0-2 cm soil samples, the slopes of the relationships were more similar at all locations because the effect of soil P stratification was minimized. Even though shallow samples did not provide a more accurate prediction of P in runoff, they did provide a more uniform prediction relationship across the different soil types and P stratification conditions. Vadas et al. (2005) reviewed the literature and combined data from 17 studies representing 30 soil types from throughout the U.S (Fig. 6). When data for soil samples taken from 0-15 or 0-20 cm in well-tilled soils were combined with data from samples taken from 0-5 cm or less in no-till and pasture soils, there was a consistent linear relationship between soil-test P and dissolved P in runoff for the majority of soils.

Therefore, shallow soil samples from P stratified soils give an assessment of soil P available to runoff that is the same as that from deeper samples in well-tilled soils.

However, it could be argued that as long as there is a predictive, linear relationship between soil-test P and runoff P, the depth for collecting soil samples is not critical if a consistent sampling depth is used. Agronomic guidelines could continue to recommend 0-15 cm samples for no-till and pasture soils with P stratification. Environmental guidelines would then use these samples for runoff P assessment, but would simply develop different interpretation systems for tilled soils and for no-till/pasture type soils, accounting for P stratification in the no-till/pasture soils. This separate environmental interpretation approach is already being investigated or implemented for P indices in some states, with Wisconsin and Missouri as examples, and represents one alternative in dealing with the soil P stratification issue. Further, soil P variability between samples may be less for deeper, agronomic samples than shallower (0-5 cm) samples due to less relative interference from thatch layers in pastures, residues on the soil surface, or seasonal variability in soil-test results (Keogh and Maples, 1967; Lockman and Malloy, 1984; Peck and Sullivan, 1993). However, more subsamples for composite samples collected within a given field or field zone could help improve accuracy of P assessments in shallow samples.

However, separate interpretation systems based on tillage, fertilization, or soil properties may be difficult for environmental soil sampling because the degree of soil P stratification can be highly variable. Data from Andraski et al. (2003b) and Mallarino and Borges (2005) demonstrate this possibility. Mallarino and Borges (2005; Fig. 3) showed that similar soil P stratification can exist between no-till and chisel-plowed soils. Data from Andraski et al. (2003b; Fig. 4) show that varying degrees of P stratification occurred between no-till and chisel-plowed soils at their three Wisconsin locations. Reasons for variable P stratification are sometimes unclear, but may be controlled by combinations of soil properties and tillage and fertilization practices. Data from Andraski et al. (2003b) and Mallarino and Borges (2005) suggest that it may be difficult to develop variable environmental soil interpretation systems because soil P stratification may vary across locations in ways that are difficult to predict. In these cases, shallow soil samples may provide the most accurate and consistent assessment of the potential for soil P transfer to runoff. Further, with each addition of P fertilizer to a P stratified soil, soil P concentrations in the 0-5 cm layer are likely to increase more than in the 5-15 cm layer. Therefore, shallow sampling offers the opportunity to make a more certain measure of soil P available to runoff, to monitor changes in soil P more closely, and to intervene with timely and appropriate management practices before the risk of P transfer to runoff increases significantly.

Recommended Soil Sampling Depth to Assess Soil Phosphorus Available to Runoff

A single, national recommendation for environmental soil sampling for P is difficult given differences in soil properties, site hydrology, management practices, and practical, logistical, or economic circumstances of different states and regions. However, the SERA-17 Committee supports the following recommendations:

1. *In soils that are consistently well-tilled and have little P stratification, a traditional agronomic soil sample taken from 0-15 or 0-20 cm, or to the depth of tillage, should accurately assess soil P that is available to runoff.*

2. *In no-till, pasture, or lightly tilled soils where distinct P stratification is likely, soil testing that accounts for soil P stratification will likely improve assessments of soil P available to runoff.*

Below, we briefly discuss two possible options to account for soil P stratification.

<u>Option a. Collect soil samples for environmental P assessment from depths shallower than the traditional 0-15 to 0-20 cm agronomic depth:</u> Because most states currently have either no guidelines for environmental soil sampling or guidelines that are the same as agronomic sampling, this option means taking separate agronomic and environmental samples. At least one state has already implemented separate agronomic and environmental sampling protocols. Existing knowledge discussed above indicates that a sampling depth of about 0-5 cm may provide the best and most consistent assessment of soil P available to runoff in P stratified soils. A different environmental interpretation system should not be needed when shallow samples are used for P stratified soils and deeper samples are used for tilled soils. Separate environmental sampling will increase soil testing costs and required resources. However, it is already recommended in several states that 0-5 to 0-10 cm samples be taken in no-till and pasture fields for agronomic P, K, lime, or herbicide recommendations. These same shallow samples could be used for runoff P assessment.

It is possible that shallow samples could also be used for agronomic recommendations. In at least one state, for example, 0-10 cm samples are used for both agronomic and environmental purposes in pasture soils. While it was recognized that 0-5 cm samples best represent the risk of P transport in runoff, the 0-10 cm sample was a best compromise between P loss assessment and the desire to avoid taking separate samples. Although some research indicates no advantage of shallow soil samples for agronomic uses, there is no evidence to suggest that sampling depths such as 0-5 or 0-10 cm predicts nutrient sufficiency for crops more poorly compared to 0-15 or 0-20 cm depths. Use of shallow samples both agronomically and environmentally implies developing field research to recalibrate both agronomic and environmental interpretations of soil P tests in some states. This process takes time and is costly.

<u>Option b. Continue to use the traditional 0-15 to 0-20 cm agronomic sampling depth and account for soil P stratification by developing different interpretation systems for P stratified soils</u>: For this option, there is no need to implement a new soil sampling system. However, separate soil-test interpretation systems should be developed for P stratified soils to improve the ability of soil-test P results from 0-15 or 0-20 cm samples to assess runoff P. Detailed research will be required to develop these different interpretation systems. Such research is currently being conducted in a few states and attempts to use data from surveys of soil P stratification and factors such as soil management and physicochemical properties to correct results for P stratification. However, soil P stratification may be quite variable across fields of a region, so that different interpretation systems may or may not be accurate for all soils suspected of having P stratification.

Although ultimately a shallow sampling depth would probably provide the best and most consistent assessment of soil P available to runoff across most conditions, it is to individual states to decide which is sampling option is best based on local research and needs. However, further research is needed on the agronomic and environmental impacts of soil sampling depth for P stratified soils, which involve crop production systems of forages, pastures, and no-till or minimum tillage management.

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Table 1. Soil test P (Mehlich-3) in four pasture soils from Texas showing a decrease in soil P concentrations with depth in the topsoil. Data are from Torbert et al. (2002).

	Soil Test P			
Soil Depth	Blanket	Windthorst	Houston	Purves
cm	mg kg^{-1}			
0-2.5	525	250	600	525
0-5	350	175	360	275
0-15	125	50	75	75

Table 2. Soil test P (water-extractable) in three tilled and no-till soils from Maryland showing the effect of tillage on soil P concentrations with depth in the topsoil. Data are from Butler and Coale (2005).

	Soil Test P					
	Beltsville		Marlboro		Queenstown	
Soil Depth	Chisel Plow	No-till	Chisel Plow	No-till	Chisel Plow	No-till
cm	mg kg^{-1}					
0-2.5	64	120	54	54	35	52
0-15	48	47	57	38	40	40
15-30	8	8	7	4	2	3

Table 3. Soil test P (Bray-1) in three tilled and no-till soils from Wisconsin showing a greater degree of soil P stratification at the third Fond du Lac location. Data are from Andraski et al. (2003).

	Soil Test P					
	Lancaster		Arlington		Fond du Lac	
Soil Depth	Range	Mean	Range	Mean	Range	Mean
cm	mg kg^{-1}					
0-2	36-138	82	5-213	34	18-274	65
0-5	36-144	80	4-195	33	18-222	59
0-15	24-152	67	3-132	27	11-89	31

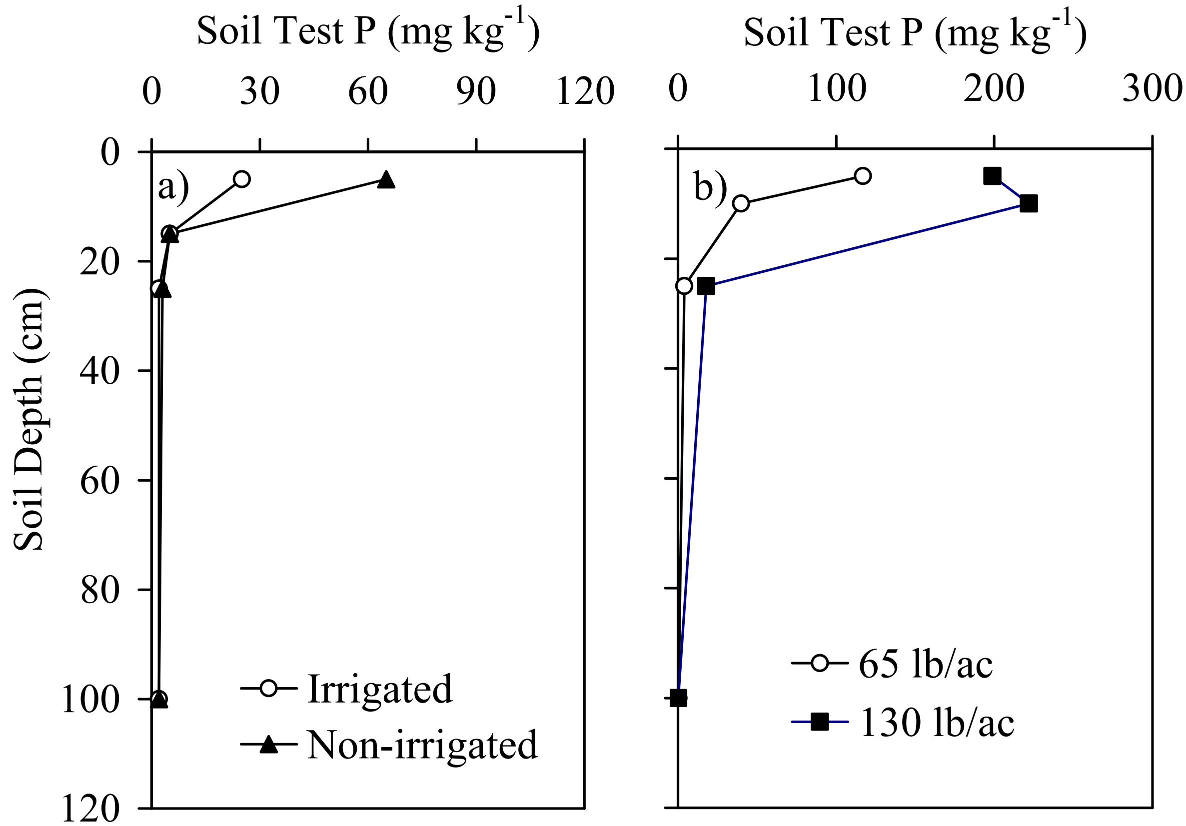

Fig. 1. Soil-test P showing common distribution of soil P with depth in agricultural soils from (a) Virginia (soil P extracted with NH_4OAc) and (b) Alberta, Canada (soil P extracted with NH_4F + H_2SO_4). Data are from Mahli et al. (2003) and Rechcigl et al. (1985).

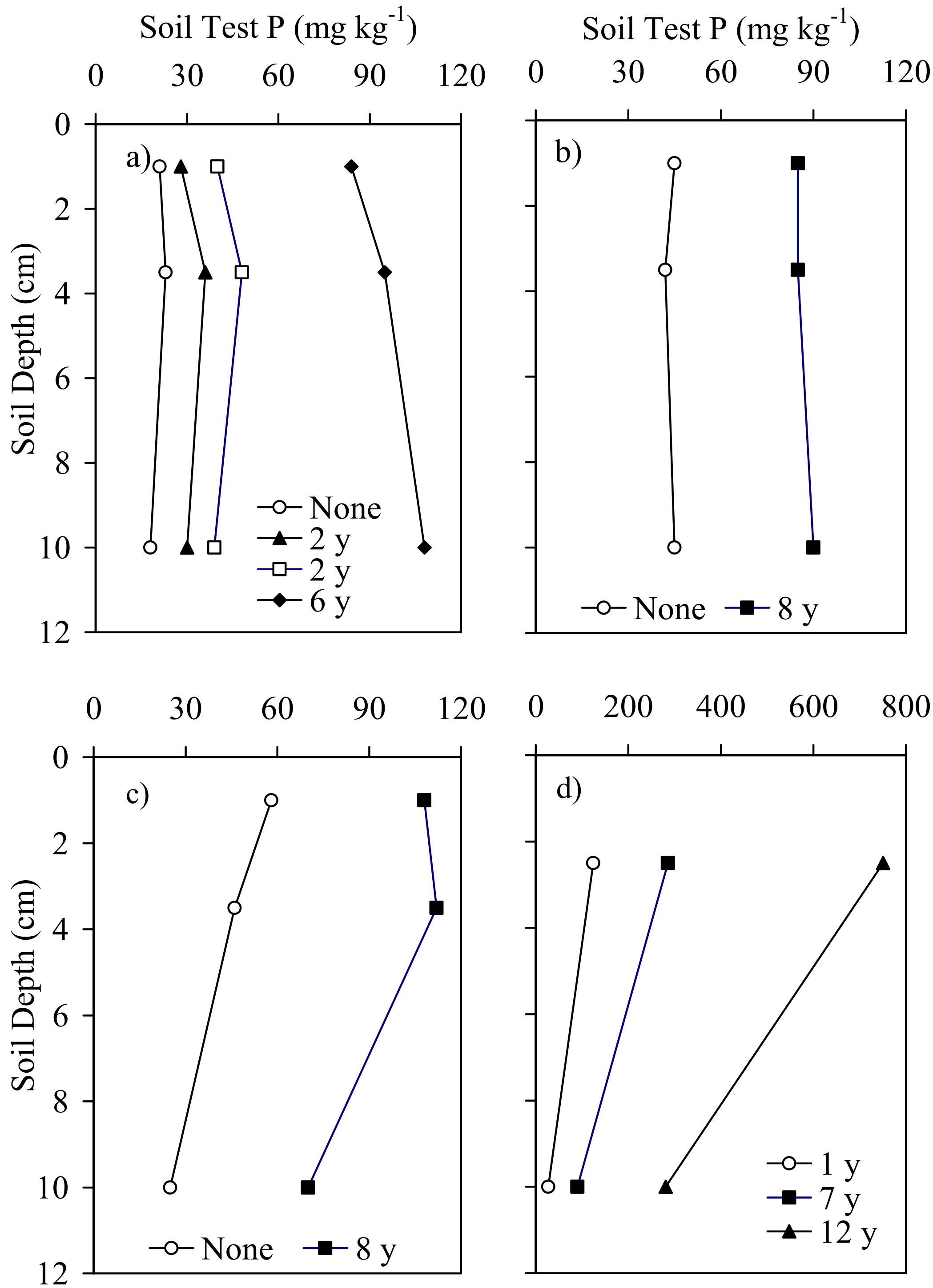

Fig. 2. Soil-test P showing (a and b) uniform distribution of soil P with depth in tilled soils from Wisconsin (Bray-1) and (c and d) decreasing soil-test P with depth in no-till and pasture soils from Wisconsin (Bray-1) and Louisiana (Bray-2). Legends indicate number of years P was applied to soils as fertilizer or manure. Data are from Andraski et al. (2003a) and Gaston et al. (2003).

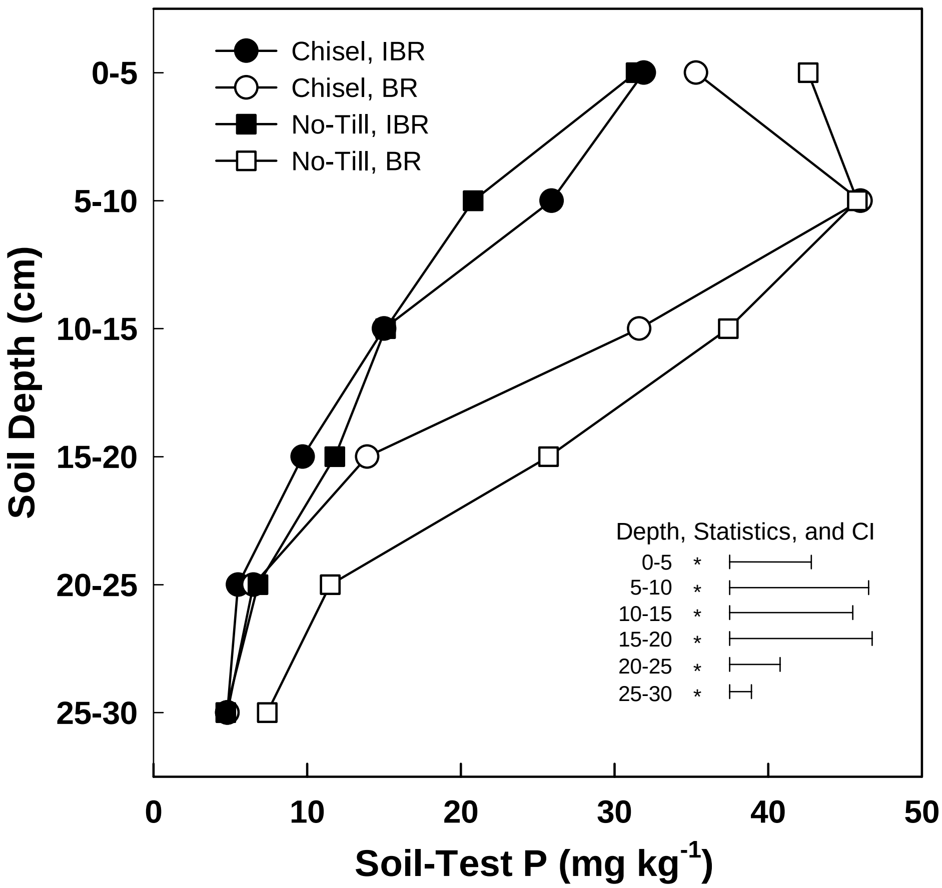

Fig. 3. Mean soil-test P (Bray-1) across five sites after 4 years of no-till or chisel-plow tillage and deep-band P fertilization (13 to 18 cm depth and spaced 76 cm) for row/band (BR) and inter-row/inter-band (IBR) sampling zones. *, significant tillage or sampling zone differences ($P \leq 0.1$). CI, confidence interval of a mean.

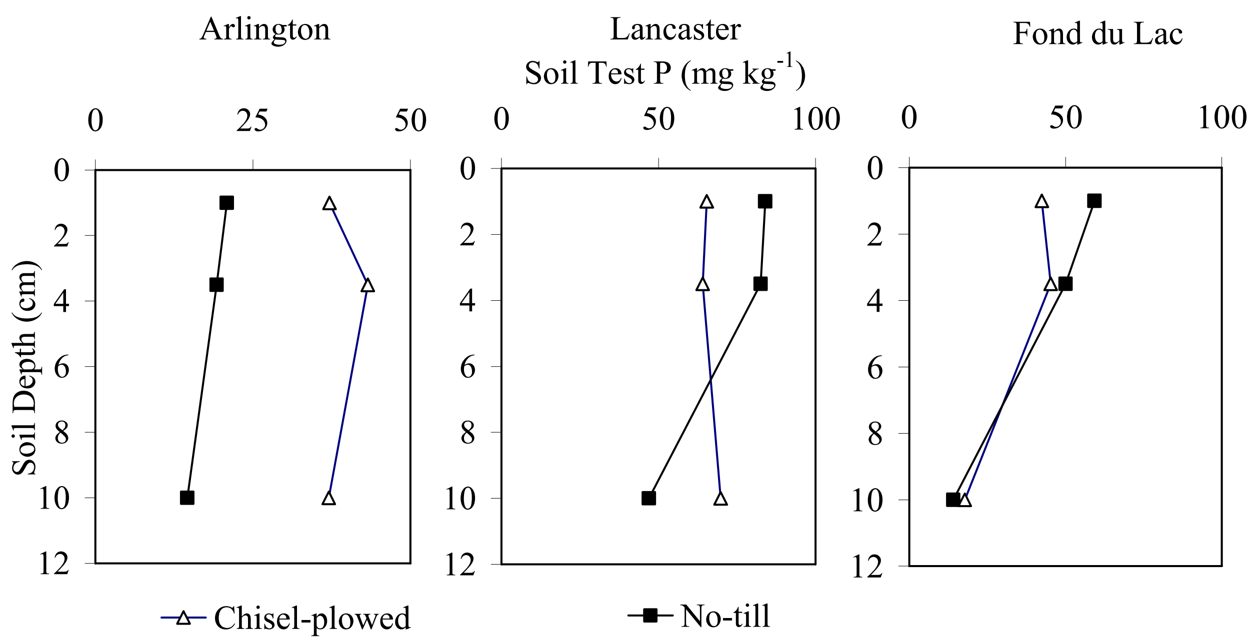

Fig. 4. Distribution of soil-test P (Bray-1) with depth in no-till and chisel plowed soils. Data are from Andraski et al. (2003b) from three sites in Wisconsin with similar fertilizer and tillage practices.

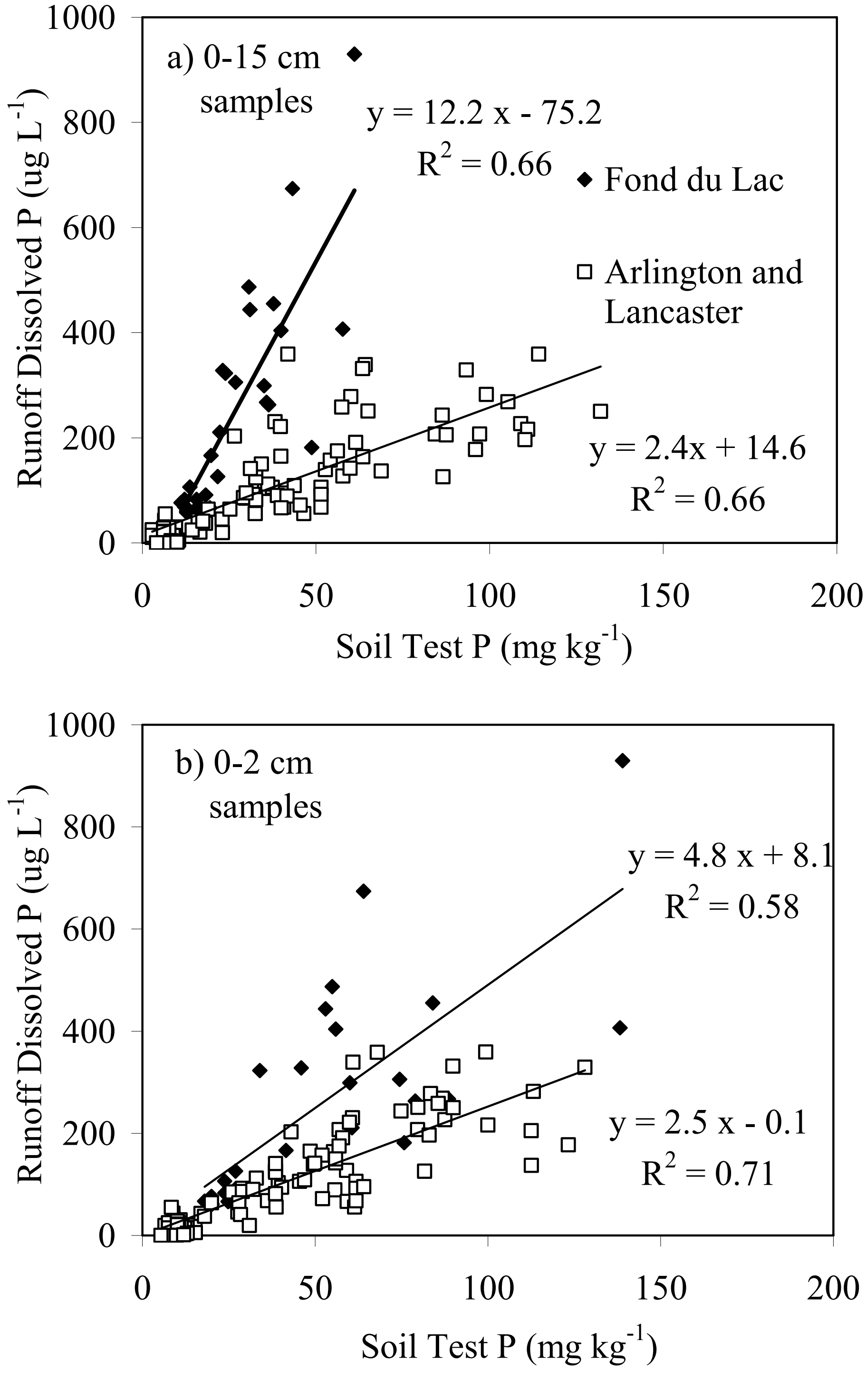

Fig. 5. Linear relationships between soil-test P (Bray-1) and dissolved P in runoff for a) 0-15 cm samples and b) 0-2 cm samples. Data are from Andraski et al. (2003b) from three sites in Wisconsin with similar fertilizer and tillage practices. Data from the Arlington and Lancaster sites with little soil P stratification behaved similarly, while data from the Fond du Lac site with greater P stratification behaved much differently.

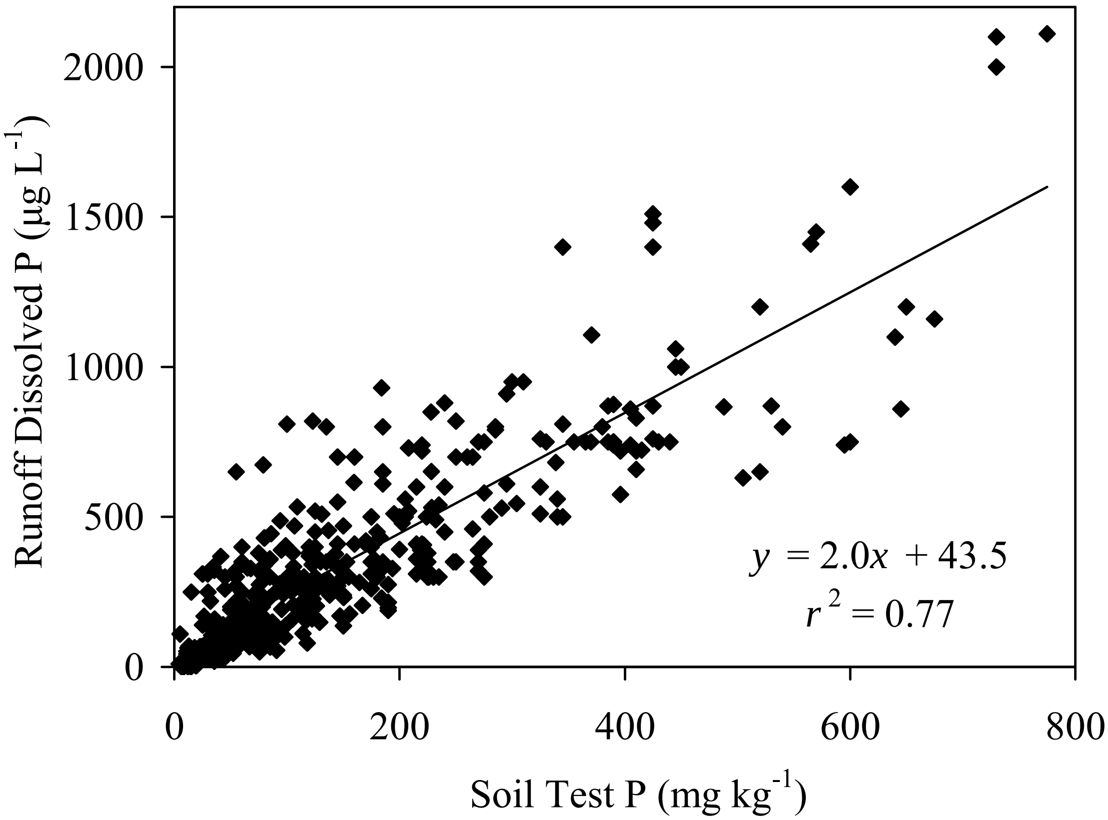

Fig. 6. The commonly observed linear relationship between soil-test P (Bray-1 and Mehlich-3) and dissolved P in runoff. Data are from a survey by Vadas et al. (2005) and represent 14 independent studies and 24 soil types. Data are a combination of samples taken from 0-15 or 0-20 cm in well-tilled soils and from 0-5 cm or less in P stratified soils, showing a consistent relationship between the two sampling depths.