SUMMARY OF P FERTILIZER USE EFFECTS ON SOIL TEST PHOSPHORUS [1]

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INTRODUCTION

Over the years, much research has centered on the use of various soil P extractants for developing soil fertility programs. While P soil test values are most reliable for estimating the historical probability of obtaining a crop response from fertilizer P application and tracking the effects of past P fertility programs - P soil tests are more commonly used as to estimate future fertilizer P rate requirements.

Depending on the objectives of a grower, P soil testing is used to predict future P rate requirements from two standpoints. One is to estimate the rate of fertilizer P that will provide for optimum economic yield return in the year of application. The other is to use P soil testing to estimate the amount of fertilizer P required to raise soil P test values to levels that will not limit crop growth and development.

Currently, many states directly or indirectly estimate the amount of fertilizer P required to build, deplete or maintain P soil test values. Illinois, for example, very clearly states that the objective of their P fertilizer use guidelines are to build soil test values to a given level depending on subsoil P status - and estimate that each 18 lbs P_2O_5/A above crop removal will raise Bray P-1 soil test values by one part per million. Iowa State guidelines generally suggest that P soil test values be maintained in the "high" range by applying the amount of P_2O_5 removed in the harvested portion of the crop.

And while North Dakota State University guidelines do not suggest building or maintaining soil test P values in any given range, they do offer that about 18 lbs P_2O_5/A will be required to build Olsen P test values by one part per million if the grower desires. Other states suggest varying amounts of P_2O_5 are required to change P soil test values.

This paper will focus on the change in P soil test values as a result of crop removal or fertilizer P addition to the soil system. Instead of providing an exhaustive research literature review on the subject, a few representative studies, current state guidelines and other information will be used to provide an overview.

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Barber (1979) reported on a 25 year crop rotation-fertility study conducted near West Lafayette, IN. Surface soil samples (0-6") collected at the beginning of the study indicated a Bray P-1 soil test of 18 ppm on the silt loam soil. Table 1 presents the average annual P_2O_5 removal for the rotation (corn-1, soybeans, wheat hay, corn-2), annual net P_2O_5 addition and soil test values at the end of 25 years. Figure 1 graphically presents the 25 year effect of P_2O_5 application/removal on Bray P-1 soil test values.

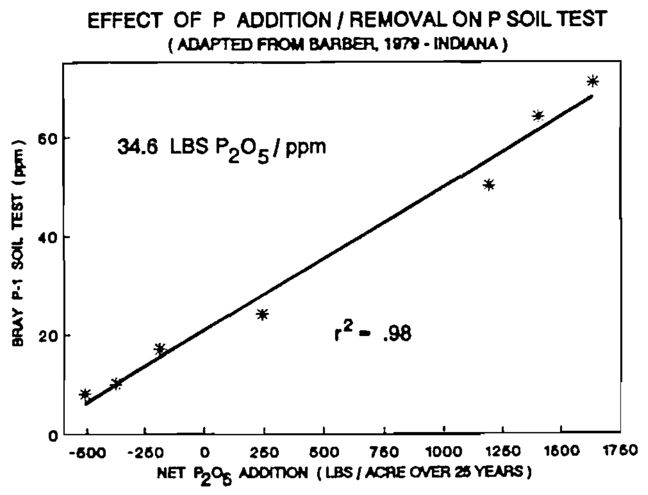
Table 1. 25 Year Cropping And P Fertilization Effects On P Soil Test Values - Indiana (Barber, 1979).

P Applied	P Removed	Net P Addition	1977 Bray P-1
- - - Lbs P_2O_5/Acre/Year - - - -			ppm
0	20.4	-20.4	8
10.2	25.1	-14.9	10
22.5	30.0	-7.5	17
45	35.3	9.6	24
90	42.2	47.5	50
100	43.9	56.1	64
110	44.7	65.5	71

While there was an excellent relationship between net P_2O_5 addition and P soil test value, over 34 lbs P_2O_5/A was required to change Bray P-1 soil test values by one part per million - much more than has generally been found in other studies.

Depth of tillage, and resulting P fertilizer incorporation, may offer a possible explanation. It is quite likely that over the course of this 25 year study that relatively deep tillage was performed. As tillage depth increases, soil P tests would be expected to be less affected by P application than with shallower tillage.

Figure 1



Based on several Illinois field studies, Peck et al. (1971) concluded that about 18 lbs P_2O_5/A were required to increase Bray P-1 soil test values one part per million. At the Elwood location, one-time P_2O_5 rates ranging from 0 to 900 lbs/A were applied to a soil having an initial soil test value of about 5 ppm Bray P-1. Soil samples were subsequently collected from the plots approximately 1, 2, 3 and 5 years after fertilizer application. A slow decrease in P soil test values were detected over the 5 years of the study. Neither crop yields or P_2O_5 removal were reported.

Figure 2 shows the effect of a one-time P_2O_5 application on soil test P one year after application (16.8 lbs P_2O_5/A/ppm Bray P-1). Figure 3 presents the relationship between net P addition and P soil test value over the five year study period, assuming 30 lbs P_2O_5/A crop removal per year. About 21.5 lbs P_2O_5/A were required to change Bray P-1 soil tests by one part per million.

Figure 2

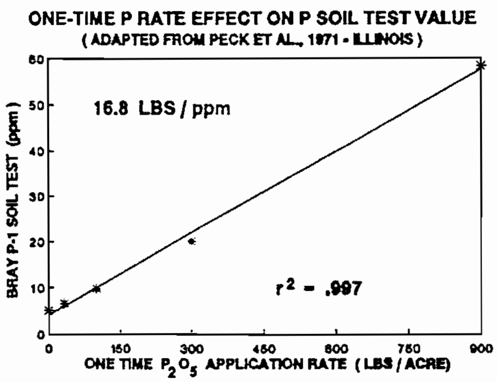
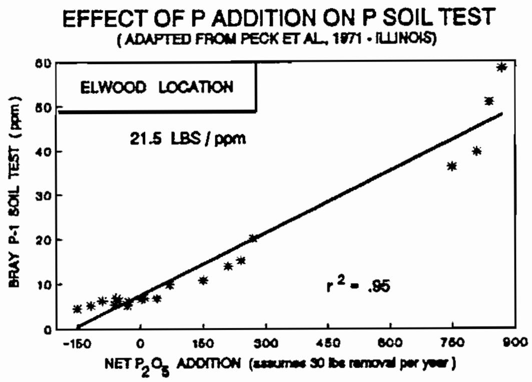


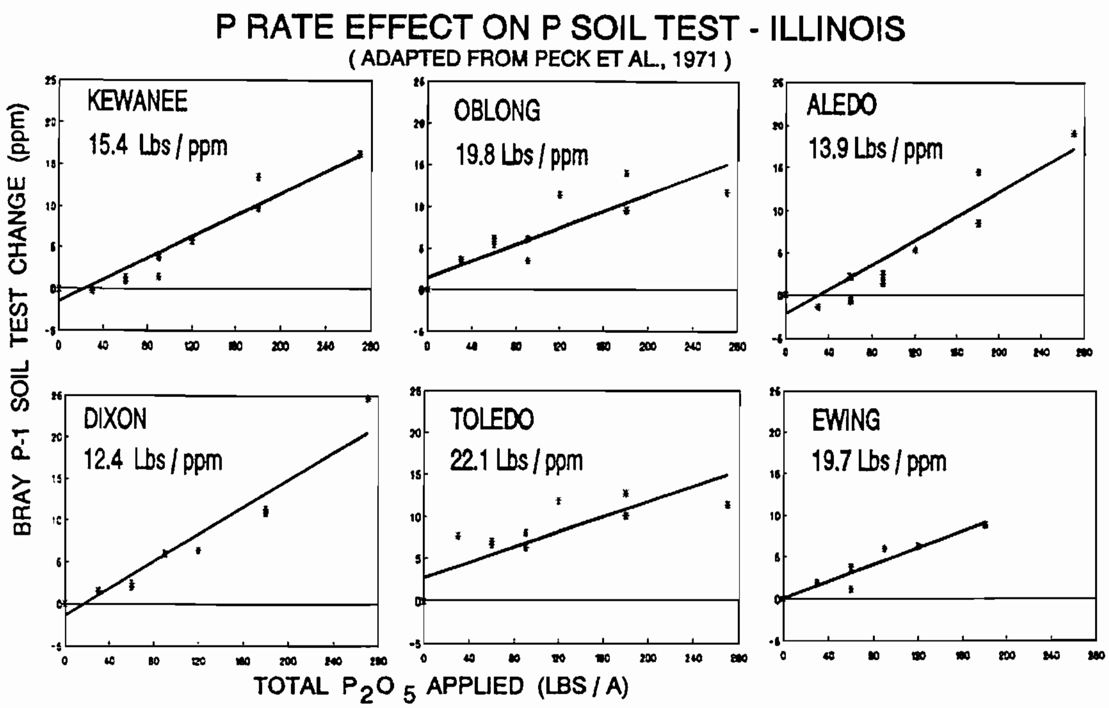
Figure 3



The effects of annual P_2O_5 rates (0, 30, 60 and 90 lbs P_2O_5/A/year) across a range of initial sample soil test values (surface soil samples) at six locations were also reported by Peck et al. When averaged across all locations, they concluded that Bray P-1 soil test value increases were proportional to the amount of fertilizer P applied and that about 18 lbs P_2O_5 were required to increase soil test values one part per million. Figure 4 presents the relationship of cumulative P_2O_5 applications to Bray P-1 soil test values at each of these locations. Again, the amount of P_2O_5 removed in the harvested portion of the crop was not included in the analysis.

These same authors reported that the equivalent of from 9 to 46 lbs P_2O_5/A were required to increase Bray P-1 soil test values by one part per million in a separate study. A range of soils were incubated for 49 weeks in the laboratory, then analyzed for Bray P-1 extractable phosphorus.

Figure 4



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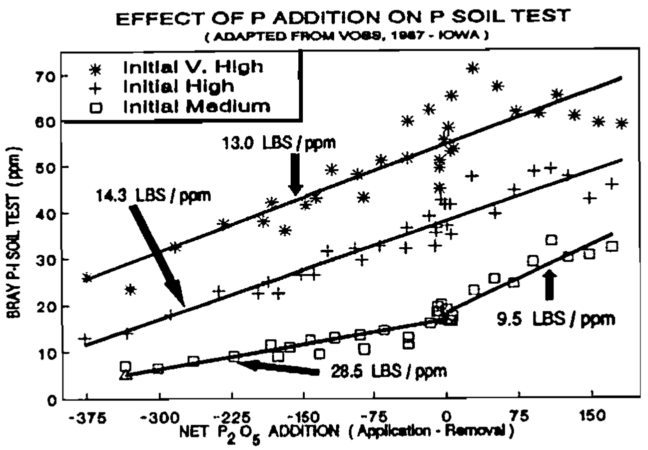
Voss (1987) summarized the results of a residual Iowa P study initiated at the Clarion-Webster Research Center. In this corn/soybean rotation study, a range of initial soil test levels (medium, high and very high) were established by single applications of P fertilizer. In subsequent years, annual P_2O_5 rates of 0, 23, 46 and 69 lbs/A were then imposed on each initial P soil test level. These annual rates were intended to estimate 0.5, 1 and 1.5 times annual average P_2O_5 crop removal. Over the time period 1976-1984, P soil test levels have declined where P_2O_5 applications have been less than crop removal, have remained essentially constant where P_2O_5 applications have approximated crop removal and have tended to increase when P_2O_5 applications have exceeded crop removal.

Figure 5 presents information relating net P_2O_5 addition (application - crop removal) to Bray P-1 soil test values. The soils initially testing high and very high in soil test P required about 13-14 lbs P_2O_5/A addition or removal to change Bray P-1 soil test values one part per million. A single linear response function appeared to fit the data reasonably well. However, soils initially testing medium in soil test P seemed decrease at a slower rate when net P_2O_5 additions were negative - 28.5 lbs P_2O_5/A removal required to lower Bray P-1 one part per million - while net P_2O_5 additions of only 9.5 lbs P_2O_5/A increased Bray P-1 soil test levels one part per million. Apparently, soil test values were approaching an equilibrium level at which soil test levels will generally remain regardless of crop removal.

Figure 5



From a broader perspective, Table 2 presents information concerning total P_2O_5 applications (fertilizer and manure), crop P_2O_5 removal, crop acres and average Bray P-1 soil test values over several time periods (R. Voss, personal communication). When evaluated over a time frame from the mid-point of the first range through the mid-point of the last range (1977-1987), P_2O_5 applications above crop removal have totaled about 160 lbs/A. Given that soil test values have increased about 9 ppm Bray P-1, this equates to about 18 lbs P_2O_5/Acre for each ppm change in soil test. While certainly not scientific, this data does support "buffer capacity" numbers used in many areas.

Table 2. Estimated Average P_2O_5 Applications, Crop P_2O_5 Removal And Soil Test Values For Iowa. (Adapted, Voss personal communication)

Year	Fertilizer Addition	Manure Addition	Crop Removal	Crop Acres	Net P_2O_5 Addition	Ave. P Test
	- - - Tons P_2O_5 Equivalent	- - -		x 1000	lbs P_2O_5/A	ppm
1974-79	440,555	207,424	378,558	24,493	22.0	24
1980-85	401,529	207,424	423,904	24,427	15.3	
1986-89	311,165	207,424	404,183	22,985	10.0	33
	Totals For 1977 - 1987			Average	Total	
1977-87	4,359,439	2,281,660	4,698,961	24,183	160.5	9 ppm Change

160 lbs P_2O_5 Added Above Removal And 9 ppm Change In Bray P-1 Soil Test - Equals 17.8 lbs P_2O_5/Acre Per PPM Change

Studies evaluating fertilizer P effects on alfalfa yield and Bray P-1 soil test values were conducted at four Wisconsin locations and reported by Kelling (personal communication). The length of these studies were six years at the Lancaster and Manitowoc locations, three years at Hancock and two years at the Ashland location. Initial Bray P-1 soil test values were 17, 35, 37, and 19 ppm for the Lancaster, Manitowoc, Hancock and Ashland locations, respectively.

Figure 6 presents the relationship between net P_2O_5 addition (total P_2O_5/A applied minus total P_2O_5 removal) and the resulting change in Bray P-1 soil test values at each location. For the purpose of this paper, crop removal was assumed to be 12 P_2O_5 per ton of alfalfa production. About 29 lbs P_2O_5/A were required to change Bray P-1 values at the Lancaster location, while only about half that amount was needed at the other locations. Across all locations, about 18.5 lbs P_2O_5/A was needed to change Bray P-1 values one part per million.

Currently, Wisconsin assigns individual P buffering values to several subsoil groups in the state. The P buffering capacity values currently used by the University of Wisconsin are largely based on laboratory studies (Ransom, L., PhD thesis) in which the soil samples were allowed to equilibrate 224 days prior to Bray P-1 soil test determination.

The resulting calculated P buffering capacity values (P_2O_5 required to effect a one ppm Bray P-1 change) are generally lower than those reported previously (Table 3). It is interesting to note the wide variations in apparent P buffering capacity for different soils. While there were general differences across subsoil groups, there were also substantial differences between soils within each subsoil group. Subsoil group 'A' includes southern "forested" medium-fine soils, 'B' includes southern "prairie" medium-fine soils, 'C' includes red medium-fine soils, 'D' includes northern medium-fine soils and 'E' includes sands/loamy sands.

Figure 6

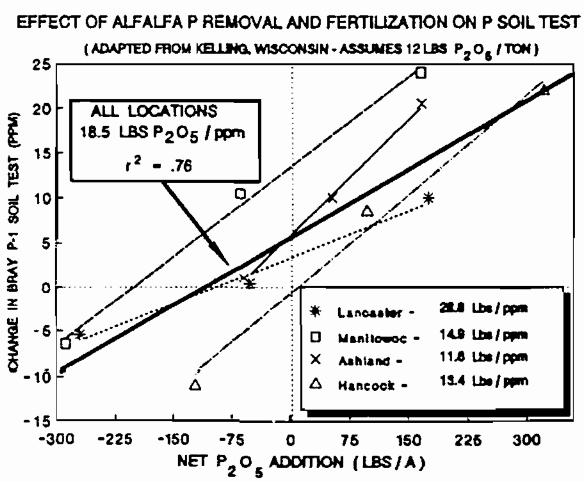
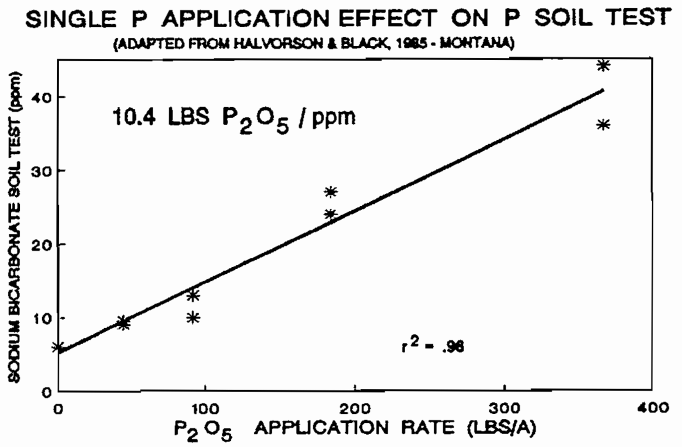


Table 3. P Buffering Capacity Values - Wisconsin

Group	P Buffering Capacity Range	P Buffering Capacity Mean
	Lbs P_2O_5/ppm Bray P-1	
A	4.6 - 14.1	8.3
B	6.6 - 8.2	7.3
C	5.2 - 25.4	9.2
D	5.4 - 24.0	10.0
E	4.0 - 8.4	6.0

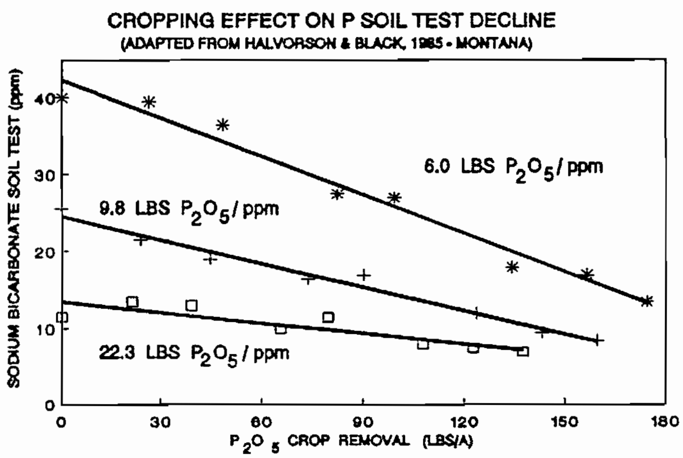
A long-term Montana study (Halvorsen and Black, 1985a, 1985b) examined the effects of one-time applications of 45, 92, 184 and 367 lbs P_2O_5/A on sodium bicarbonate extractable soil P (0-6") and P_2O_5 recovery in subsequent crops. Eleven crops over a seventeen year period were included. It is worth noting that only shallow tillage (3-4 inches deep) was performed over the life of the study.

Figure 7



Initially, the P soil test was 6 ppm and was linearly increased with each increment of added P fertilizer. Sodium bicarbonate P soil test values increased one ppm for each 10.4 lbs P_2O_5/A applied (Figure 7).

Figure 8

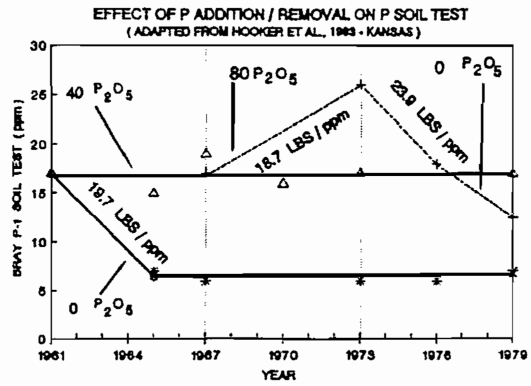


With subsequent cropping, P soil test values declined with each successive crop and the authors observed that a new soil P equilibrium seemed to be developing after the seventh crop was harvested. Figure 8 shows relates the total P_2O_5/A removed in the first seven crops and the resulting sodium bicarbonate P soil test values.

Sodium bicarbonate P soil test values declined at a faster rate (less P_2O_5 removal per one ppm decline) at higher soil test values. Where the initially established P soil test value was about 40 ppm, each six pound increment of crop P_2O_5 removal decreased the P soil test by one part per million. About 9.8 lbs P_2O_5/a crop removal was required to decrease soil test P one part per million at the intermediate soil test level and over 22 lbs P_2O_5/A crop removal was needed to reduces soil P test levels one part per million at the lowest established P test level. Sodium bicarbonate soil test values remained at about 6 ppm over the length of the study when no P fertilizer was applied.

Hooker et al. (1983) summarized a long-term study looking the effects of annual P applications on corn grain yield and P soil test values. Initially, this silt loam site had a pH of 7.9 and a Bray P-1 soil test value of 17 parts per million. The following information assumes 0.375 lbs P_2O_5/bu removed in the corn grain (Figure 9).

Figure 9



Four years after initiation of this study, P soil test values dropped to about 6-7 ppm when no fertilizer P was applied and have remained at that level through the life of the study. This initial decrease in P soil test amounted to 19.7 lbs P_2O_5 crop removal for each one part per million decrease.

The application of 40 lbs P_2O_5/A, on the other hand, essentially maintained the initial 17 ppm Bray P-1 soil test value. From 1967 through 1973 some plots in this study received an additional 40 lbs P_2O_5/A (for a total 80 lbs P_2O_5/A application). Net P_2O_5 addition during this time period increased soil test values to about 26 ppm - or an increase of one ppm Bray P-1 for each 18.7 lbs P_2O_5/A application above crop removal (Figure 9). When P applications were eliminated on plots receiving the 80 lbs P_2O_5/A treatment for six years, soil P tests declined to about 12.5 ppm in 1979 - one ppm decline per 23.9 lbs P_2O_5/A net removal.

Figure 10

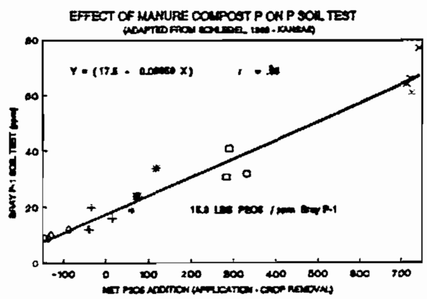


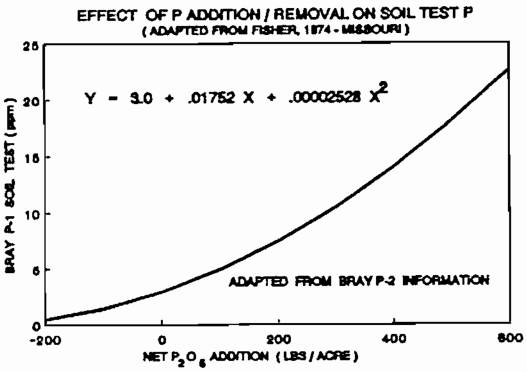
Figure 10 summarizes information on another Tribune, KS study. (Schlegel 1990). Composted manure containing about 0.9% P was annually applied at rates of 0.9, 1.8, 3.6 and 7.2 ton/A for three years. Initial soil samples (0-6") indicated a 13 ppm Bray P-1 soil test phosphorus.

The relationship between net P_2O_5 application (application - removal) and P soil test values after three years indicates a good linear relationship - with about 15 lbs net P_2O_5/A addition required to change Bray P-1 soil test values one part per million. These studies suggest little or no difference between organic and inorganic P sources relative to P test changes.

Fisher (1974) established a curvilinear relationship between net P_2O_5 addition and Bray P-2 soil test value. From other information in the same publication, this relationship to Bray P-1 soil test P has been adapted (Figure 11). These results are based on work conducted in southwest Missouri from 1966 through 1970 with an alfalfa-orchard grass mixture.

Current Missouri guidelines reflect this curvilinear relationship. They suggest a range of from 16 to 28.8 lbs P_2O_5/A above crop removal to increase Bray P-1 values by one part per million, depending on the target soil test level and the existing soil test value (Buchholz, 1983).

Figure 11



SUMMARY

The effect of P fertilizer addition on extractable P soil test values varies and is difficult to predict. In general, field studies have often indicate that more P_2O_5 is required to effect a change in soil test values than have laboratory studies. Field research often shows a need for about 14-22 lbs P_2O_5/A to change Bray P-1 soil tests by one part per million - although 34 lbs P_2O_5 were required in a long term Indiana study and less was required in others. Wisconsin, Missouri (Aquino, 1984) and Kansas (Pothuluri, 1991) laboratory studies point this out.

There are many factors that affect the apparent amount of P_2O_5 required to change (either up or down) extractable P soil test levels. The depth from which soil samples are collected and the depth to which applied P is incorporated are very important considerations. Deep tillage mixes applied P_2O_5 with a larger volume of soil and will result in less change. Conversely, shallow tillage would reduce the soil volume affected. This may help explain some of the differences between field and laboratory results.

Higher initial soil test levels will sometimes, not always,require less P_2O_5 removal to reduce P soil test values than lower soil test levels in a given study. Soils will maintain some equilibrium level below which it is unlikely that soil tests will fall. Failure to take this into account will affect the results if the decline of soil tests are monitored.

The best way to determine the amount of P_2O_5 required to effect a desired change in extractable P soil test values would seem to be to monitor soil test values with a sound, comprehensive soil sampling program. After all, soil testing is better at documenting the effect of past management than at predicting future needs.

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