Prediction of the Residual Effect of Phosphate Applications[1]

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When crops are fertilized with phosphorus, they frequently use less than twenty per cent of the added phosphorus. The phosphorus not used by the first crop remains in the soil and has been shown to affect the nutrition of the subsequent crops grown on this soil (3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15). This residual phosphorus may also affect the level of available phosphorus as indicated by soil tests (4), (6). Because of this residual effect, the complete evaluation of a phosphorus application includes not only the increase in yield of the immediate crop but the benefits to be derived by all succeeding crops. The need for this evaluation becomes increasingly important where fertilization is made on the basis of large applications applied once every three or four years rather than applications applied for each crop.

In this paper, the author presents a method which has been found useful in Indiana for predicting the residual effectiveness of phosphorus fertilizer applications. This method was developed in the course of a systematic study concerning the effect of the available phosphorus level in the soil on the response of crops to phosphorus additions.

In this paper the terms, available phosphate, fixed phosphate and residual phosphate, are used with the following meaning. Available phosphorus is that phosphorus removed from the soil by 0.7 N HCl with a soil: solution ratio of 1:3 during a shaking period of two minutes on a reciprocating shaker. Phosphorus applied to the soil and not recovered by this extraction procedure is termed fixed phosphorus. Residual phosphorus is that which exerts an effect on the second and succeeding crops over and above the effect of the original available phosphorus present in the soil.

The available phosphorus as defined above is correlated with the soil phosphorus that is available to the plant. The correlation between the relative response to phosphorus fertilizer and the soil test for available phosphorus is shown in figure 1. The data used in figure 1 are from a series of replicated field experiments on alfalfa conducted in 1950. The treatments used were (1) an application of 200 pounds of P_2O_5 and 200 pounds of K_2O (this treatment was assumed to give the maximum yield obtainable from applications of phosphorus), and (2) a treatment where only 200 pounds of K_2O was applied (this gave the yield without phosphorus).

In subsequent studies, the relative response to phosphorus at a given soil test level was found to vary from year to year (1). In some years very little response occurs, whereas, in other years exceptionally large responses occur. A variability also occurs when different soil populations are used (2). Data shown here are for one year only to

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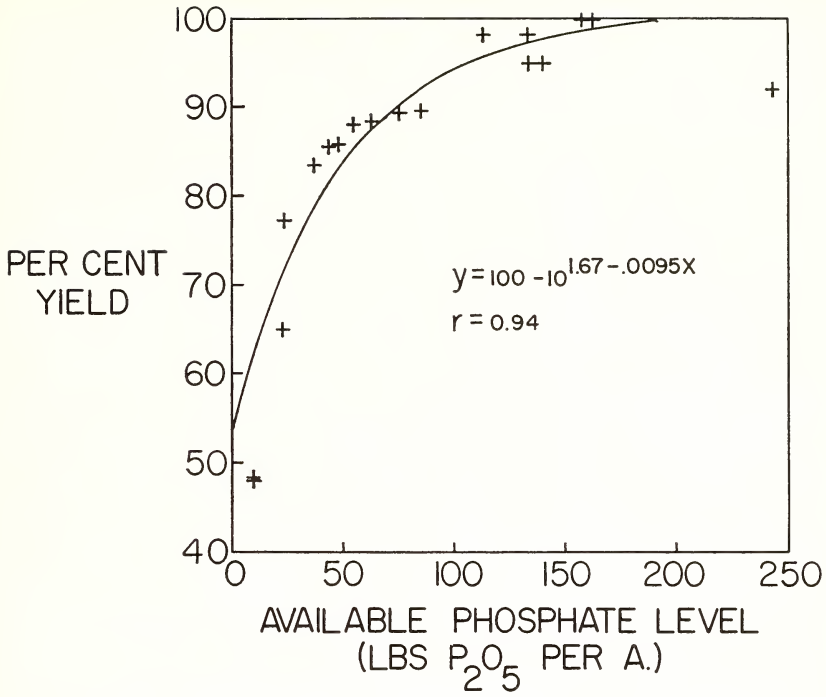

Figure 1. The relationship between available phosphate and relative yield.

eliminate the variation due to years and for soils which respond similarly to phosphorus. The soil types used were: Switzerland, Elkinsville, Cincinnati, Rossmayne, Wheeling, Avonberg, Holston, Bedford, Fredrick, Vigo, and Gibson. In this example a correlation coefficient of 0.94 was obtained by using a linear regression of the log of the yield decrement versus the soil test.

Figure 1 indicates the relationship between the relative yield of the crop that is not phosphate fertilized and soil tests from fields where no heavy phosphate applications had been made in recent years. For the soil test to be of value in determining the residual phosphorus, soils where the soil test reflects residual phosphorus should follow the same regression line as those in which the available phosphorus was primarily in the native form. To investigate this point, a greenhouse experiment was conducted using soils collected from experimental plots where the available phosphorus level had been altered by heavy applications of phosphate two or more years prior to sampling. The soil types used were: Toronto, Raub, Vigo, Parke, Miami, and Reesville. The soils were fertilized at the rate of 200 pounds of N and 200 pounds of K_2O per two million pounds of soil. They were placed in number 10 cans in a randomized block design with four replications. Millet was grown for six weeks, then harvested and the above ground portion of the plant analyzed for phosphorus. The total uptake of phosphorus was determined from the yield and phosphorus content. The uptake of phosphorus

obtained in this manner has been shown to be a reliable indicator of the available soil phosphorus (2). The uptake of soil phosphorus plotted against soil test is shown in figure 2. A correlation coefficient of 0.94 indicates that the soil test is a good indicator of the residual phosphorus in these soils.

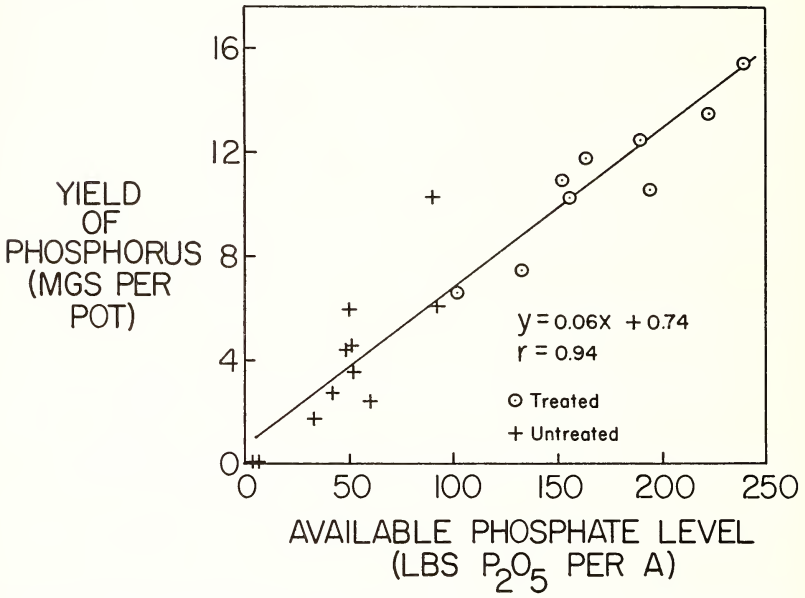

Figure 2. The correlation of yield of P with soil test on soils varying in previous phosphate treatments.

Since the soil test measures the residual phosphorus in the soil, the next step was the determination of the relationship between phosphate applications and the increase in soil test for available phosphate. It was proposed that the available phosphorus measured by the soil test procedure reflects the phosphorus equilibrium in the soil and consequently can be used to predict the amount that the available phosphorus level will be increased when phosphorus applications are made. That is, there is an equilibrium in the soil between available phosphorus and the factors which tend to fix phosphorus. The greater the amount of unsatisfied "phosphorus fixers" the smaller the amount of available phosphorus found in the particular soil and vice versa. To test this hypothesis, soil test data were collected from experiments having large phosphate applications. The differences in the soil test between the 0 phosphate and the phosphate-treated plots were determined. Samples were taken from both field and greenhouse experiments. The time which had elapsed between phosphate application and soil sampling varied from 4 to 14 months. In well mixed samples, equilibrium was obtained in one month. This increase was significantly correlated with the soil test of the untreated soils and is shown in figure 3. The logarithmic relationship gave a significantly higher correlation coefficient than the linear relationship.

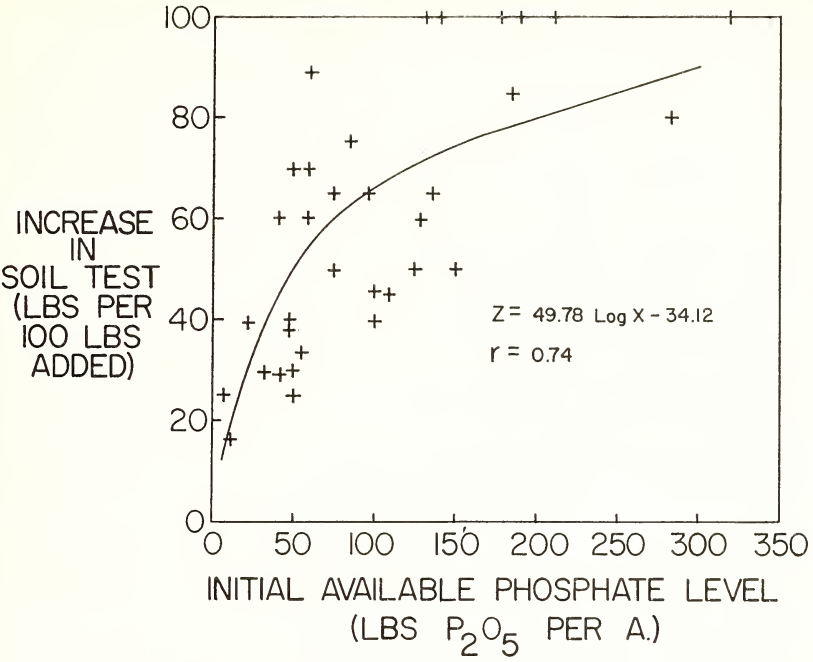

Figure 3. Increase due to 100 lbs. of P_2O_5 as related to available phosphate level.

These data support the hypothesis that the soil test can be used to predict the amount by which the available phosphorus is increased by phosphate applications.

According to this hypothesis, differences due to soil type, clay content, organic matter level, and pH are reflected in the initial equilibrium level of available phosphorus. To test this one step further, a laboratory experiment using 24 Indiana soils was set up to determine if these factors significantly affected the correlation of increase in phosphorus soil test from an application of phosphate with soil test. The soil types used were: Newton, Tracy, Door, Odell, Chalmers, Strole, Genesee, Crosby, Julian and Maumee. The ranges of the variables used were: pH, 4.8 to 6.7; organic matter, 1.3 to 11.5%; clay, 12.9 to 42.3%. Fifty-gram samples of soil were incubated with phosphate applied at the rates equivalent to 0, 100, 200, and 400 pounds of P_2O_5 per 2 million lbs. of soil at 20% moisture. The soils were analyzed after 4 weeks and 16 weeks. The values at 16 weeks were not significantly different from those for four weeks. A multiple regression analysis was made using the increase in test as the dependent variable and the soil test for phosphorus, the pH, the organic matter level, and the clay content as independent variables. Only phosphate soil test and pH gave significant correlations. An r^2 value of 0.19 was obtained for the correlation of the soil test increase with the initial soil test. Inclusion of pH increased the value to 0.27. The prediction equation was $Y = 45.1 + 0.164X_1 - 1,236X_2$,

where X_1 is the phosphate soil test value and X_2 is the pH. With this group of soils, much of the variation is unexplained by these two variables. Differences due to soil type were difficult to determine since there were only a few soils from each soil type in the soils used. These soils were stored dry since their use in another project and this may have caused the low correlation coefficient. The results with these soils support the hypothesis studied with respect to organic matter and clay content. The effect of organic matter and clay content on phosphate build-up from a phosphate application either has no effect or is reflected in the initial soil test level. However, the soil pH exerts an effect in addition to any effect which it may exert through the soil test for phosphorus on the untreated soil. The effect of pH in this case indicates a decrease in phosphate build up as pH is increased. This is the opposite to normal beliefs.

The relationship of the increase in available phosphate from an application of phosphate with soil test can be substituted into the first relationship presented, the correlation of percent yield with soil test, to show the residual effect of phosphate in terms of yield.

The percent yield (y_1), as previously defined, is related to the soil test for phosphate by the equation:

$$y_1 = 100 - 10\ 1.67 - .0095x \quad (1)$$

when 100 pounds of P_2O_5 are added to the soil the increase in the phosphate soil test (Z) is related to the initial soil test (x) by the equation:

$$Z = 49.78 \log x - 34.12 \quad (2)$$

The percent yield (y_2) after 100 pounds have been added and come to equilibrium (y_2) would then be:

$$y_2 = 100 - 10\ 1.67 - .0095\ (x + 49.78 \log x - 34.12) \quad (3)$$

The increase in yield ($\triangle y$) due to the residual effect of this phos-

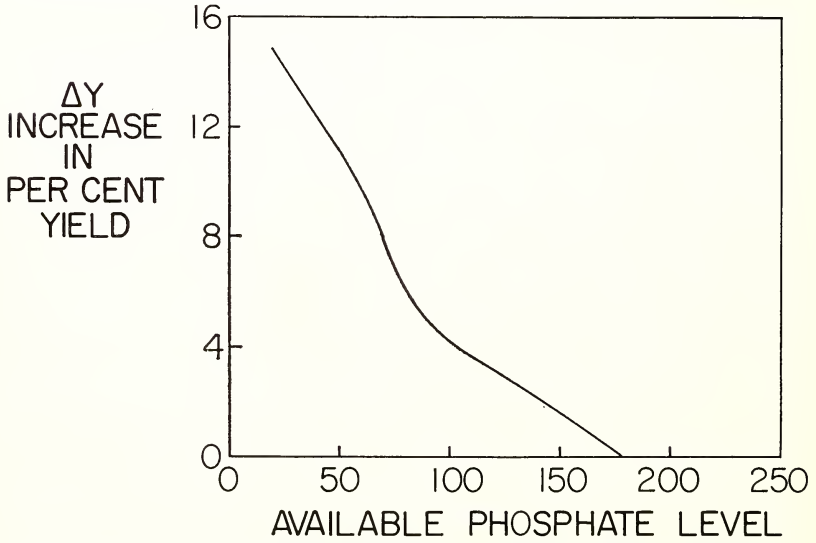

Figure 4. The residual effect of 100 lbs. of applied phosphate in terms of percent yield as affected by the available phosphate in the soil.

phate application can be obtained by subtracting equation (3) from equation (1) which gives:

$$\triangle y = 10\ 1.67 - .0095x - 10\ 1.67 - .0095\ (x + 49.78 \log x - 34.12)$$

This expression is shown graphically in figure 4. The values shown here are the maximum for the first crop grown where residual phosphate is present. This difference would decrease as residual phosphorus is removed by successive cropping, unless maintenance applications of phosphate are made.

An important relationship from this study, shown in figure 4, indicates that in the soil test range for available phosphate of 20 to 200, *the lower the soil test, the larger the residual effect of the applied phosphate.* This is the relationship on the Indiana soils used, and it is dependent on the relative slope and position of the curves shown in figures 1 and 3. If the soils fixed larger amounts of phosphorus at the same level of available phosphorus in the soil, the residual effect would be reduced.

The concept presented is useful in determining the relative merits of building up levels of available phosphate on those soils which are low initially. It also is a method for determining the information needed to evaluate the residual effect of a fertilizer application.

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