

AN EXPLANATION OF THE THEORY OF SOIL PHOSPHATE  
ISOTHERMS AND THEIR APPLICATION

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In a period of high fertilizer costs and short supplies it is essential that we find ways to realize the maximum potential of fertilizer without waste. Soil and plant tissue tests have been used in an attempt to accomplish efficient fertilizer use. Phosphorus added to soils is usually made less soluble by reactions with calcium, aluminum, and iron. These elements may be contained in the soil solution and react with phosphate to form slightly soluble precipitates or they may be part of compounds on which phosphate is adsorbed. Several factors determine the flow of P to plant roots, namely, intensity, quantity, capacity and mobility. In its simplest form the intensity factor can be represented as P concentration in the soil solution. The quantity factor is the amount of labile P (or P readily undergoing chemical change) in soils. A capacity factor is the quantity of P retained at specified conditions of intensity. It indicates the phosphorus buffering capacity of soils and the ability of soils to maintain intensity during P depletion. Mobility includes a number of rate factors involved in the dissolution of P associated with the solid phase, transport of P to plant roots, and uptake of P by plants.

A graphic representation of the intensity and capacity factors are presented in figure 1. These two soils have the same intensity or P concentration in the soil solution but have widely different capacities to buffer P and maintain the intensity factor. The common and most widely used soil P tests give a measure of only the intensity factor. If these two soils were tested for P by these methods and we assume the P concentrations of these soils were less than that needed for maximum crop production, then P would be added to the soils to obtain maximum yield. Since the soil test value would be the same for both soils, an equal amount of P fertilizer would be recommended for each soil. However, the intensity or P concentration would be increased much more in soil 2 than in soil 1 with equal amounts of fertilizer P applied. These conditions may result in adequate levels of P for soil 2, while P deficiencies may still occur in soil 1. This illustrates the problem which makes evaluation of the P status of an array of soils difficult with current soil P tests. Any soil test used to predict the amounts of P needed to adjust the soil P level to an adequate level for crop production must consider the capacity and intensity factors if it is to be successful for a wide range of soils.

Such a test has been suggested and tested by soil scientists world wide in such diverse places as Australia, Hawaii, North Carolina, Idaho, and Arizona. The test consists of equilibrating sub-samples of the soil with various concentrations of P in 0.01M CaCl<sub>2</sub>. The time of equilibration is usually 6 to 7 days. At the end of the equilibration period the amount of P left in solution is measured and the amount of P sorbed by the soil sample calculated. When values for P sorbed are plotted against log P remaining in solution, approximately straight-line curves are obtained. These curves are called phosphate sorption isotherms. Figure 2 presents an illustration of a phosphate sorption isotherm. The curve is a characteristic of the soil sampled. The slope of the curve is indicative of the phosphate buffering capacity and the intercept at zero phosphate sorption is an estimate of P concentration in the soil solution.

In order to best use the phosphate isotherm for predicting P fertilizer needs, the level of P in the soil solution required for maximum plant growth must be known. Since this value changes from crop to crop it must be determined for each crop. This is done by growing the crop on soils which have had fertilizer P applied to adjust the soil P concentration to various levels. Figure 3 shows the relative yields from such an experiment plotted against the adjusted soil P concentrations. In order to achieve 95 percent relative yield for this crop (lettuce), a soil P solution level of 0.4 ppm would be required. If we use this value in conjunction with the P sorption isotherm in figure 2 we find that 55 ppm P would have to be

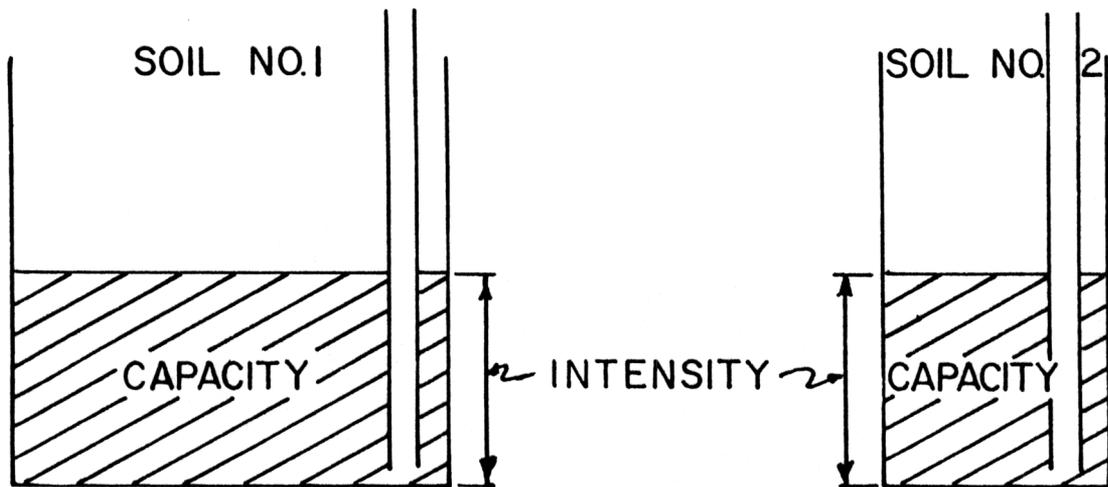


Figure 1. A graphic representation of the intensity and capacity factor of soils.

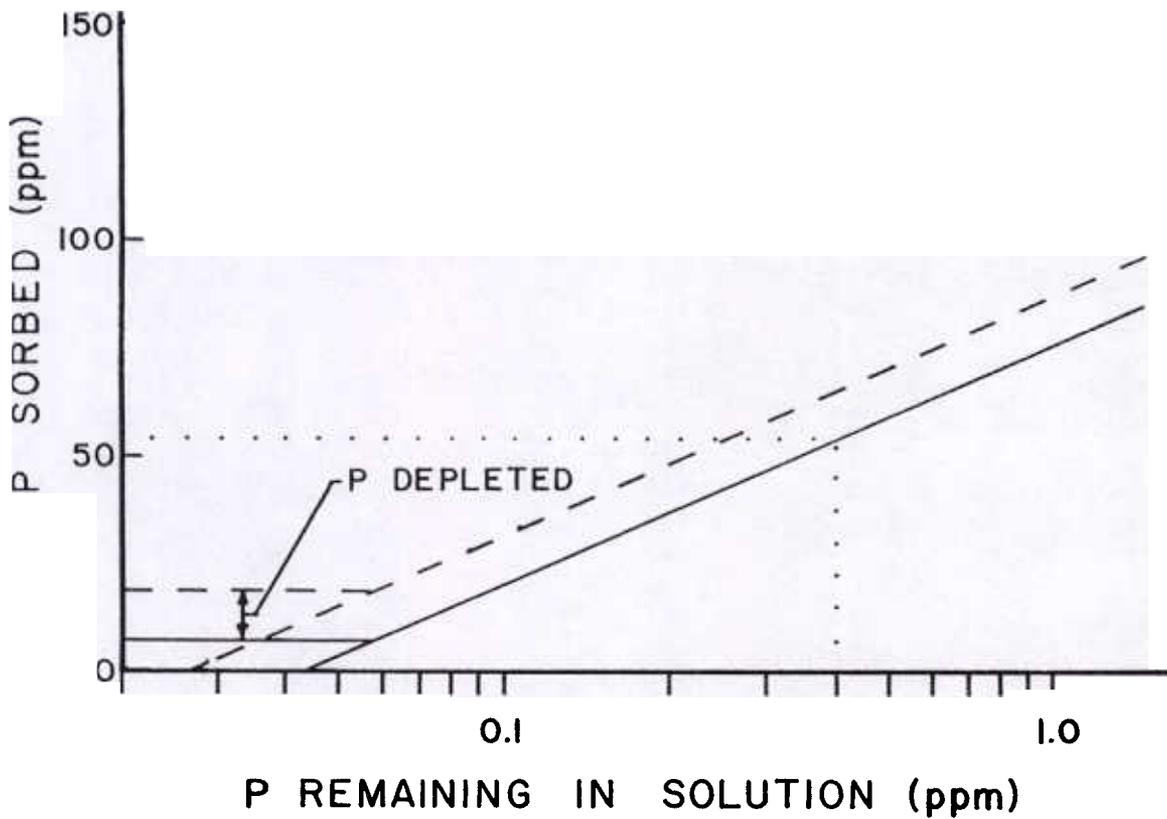


Figure 2. A soil phosphate sorption isotherm.

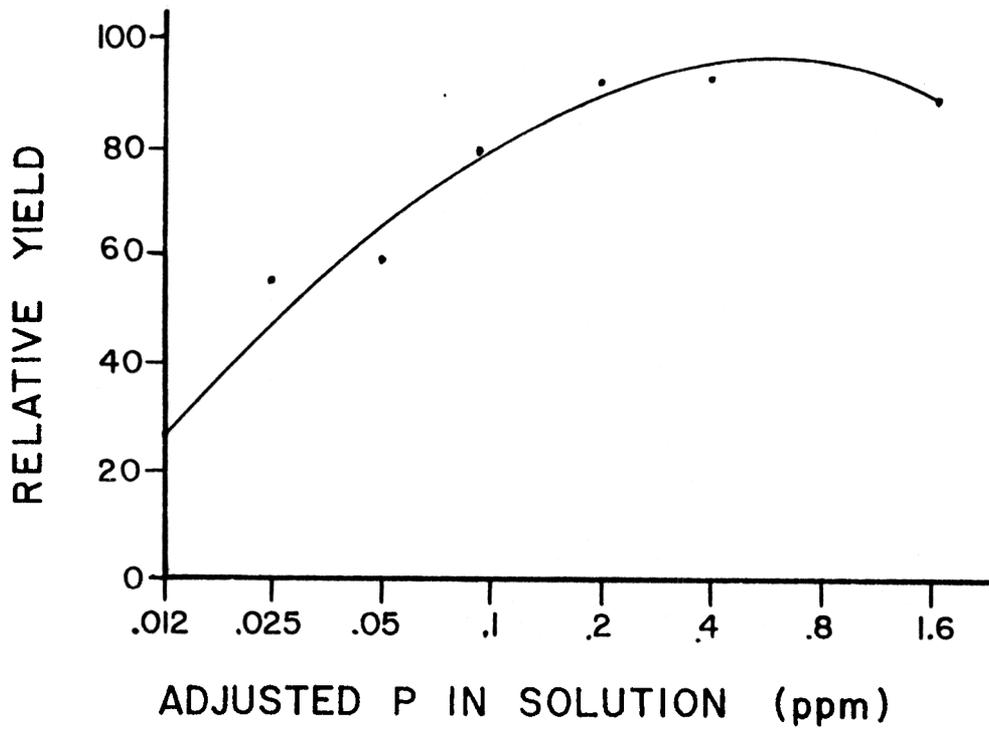


Figure 3. The relationship of relative yield to adjusted P levels in the soil solution.

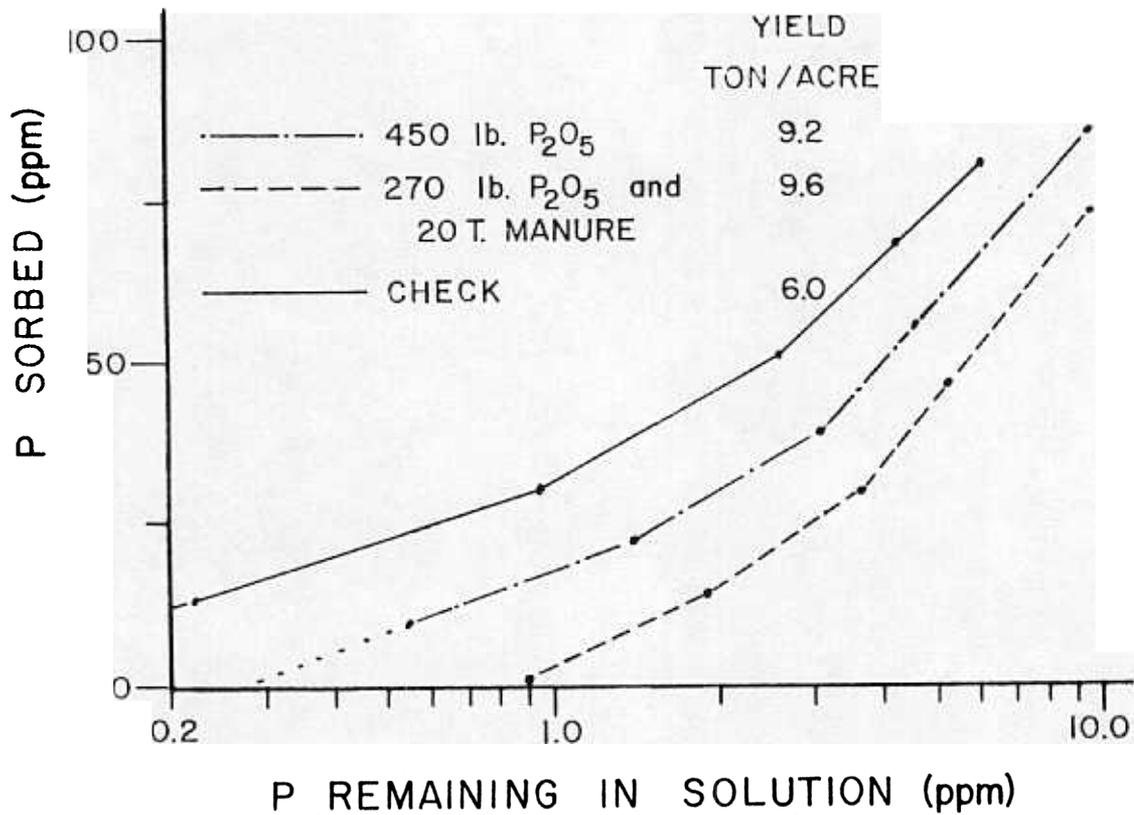


Figure 4. The influence of fertilizer P and manure applications on the phosphate sorption isotherm of soil which was cropped to alfalfa.

added to this soil in order to adjust the soil solution to 0.4 ppm. Since the amount of soil to be treated is known, we can calculate the exact amount of fertilizer to apply. The critical soil P levels that have been established appear to be the same world wide. That is, it takes the same concentration of soil P to grow corn in Hawaiian soils as it does to grow corn in Idaho soils. Temperature is about the only factor that substantially affects this value. However, there is good evidence that it will be relatively easy to adjust these values to different soil temperature growing conditions.

Another use of the P sorption isotherm is illustrated in figure 2. The dotted isotherm represents the status of the same soil after a crop has been harvested. The difference in P sorbed between these isotherms represents the amount of P used by the crop. If this information is obtained for a crop such as alfalfa, we can use it to predict the amount of P needed for the entire growth period of the crop. Before the stand is established we can sample the soil, construct a P sorption isotherm, calculate the amount of P needed to adjust the soil level to the critical level for alfalfa and then add the amount of P that will be removed during the time the alfalfa stand is maintained.

The data presented in figure 4 are from an alfalfa experiment in which the first cutting was made in 1969. The fertilizer was applied preplant and as top-dress applications. The yields were from the 1972 season and the isotherms were constructed from soil samples taken in the spring of 1973. While we have yet to establish the critical soil P level for alfalfa as described in figure 3, we can assume that it will fall between the intercepts of the check and the 450 lb  $P_2O_5$  isotherms with the zero P sorption. It is interesting to note that the curves are parallel and the isotherms move left with P removal and right with P applications.

When P sorption isotherms are used in conjunction with critical soil P solution levels it will be possible to predict P fertilizer requirements for any level of relative yield. The P sorption isotherm will allow us not only to determine when P is needed but to calculate how much fertilizer P should be applied.