Minnesota Department of Agriculture

Pesticide & Fertilizer Management

AFREC FINAL REPORT

FOR THE PROJECT LISTED BELOW

PROJECT NUMBER: AFERC ID R2017-10, Contract #122080, SPA #64940, PO#22927
(include AFREC ID, MDA Contract #, SPA#)

PROJECT DESCRIPTION: The Nature of Phosphorus Behavior in Soils

REPORT DUE DATE: On or before **May 31, 2018**

PRINCIPAL INVESTIGATOR: Paulo Pagliari

ORGANIZATION: University of Minnesota

EMAIL: pagli005@umn.edu

Abstract

Understanding soil phosphorus (P) and what soil properties affect P availability in soil is crucial to improving P management in land used for agriculture. Over the last century soil P has been the focus of innumerous scientific articles, which has helped in the development of current strategies for P management. Currently, two different mechanisms are used to study soil P, one focus on soil P buffer capacity (PBC) and the other focus on the parameters sorption maximum and sorption strength. Both mechanisms are extremely important in developing a good understanding of P dynamics in soils. However, there is no research in the literature that has provided a link between the two mechanisms. In addition, there is no research that has reported what soil property/properties controls soil PBC and the sorption maximum and sorption strength. Although some researchers have hypothesis, there are no concrete evidences that prove or disprove any of those hypothesis. Therefore, the objective of this research was to try and relate the soil PBC to sorption maximum and sorption strength and also determine which soil property/properties controls these parameters. This research project has been broken into two separate studies because of the funding strategy used by AFREC. This section dealt with the PBC, while the on going research deals with the sorption parameters.

Introduction

Researchers have used two different concepts to study the chemistry of phosphorus (P) in soils. One is related to the P buffer capacity (PBC) and the second is related to the sorption maximum and sorption strength. The PBC is defined as the amount of inorganic P in mg kg^{-1} soil (ppm) required to increase soil test P by 1 ppm. The greater the PBC value of a soil is, the greater the amount of P that must be added to increase the STP by unit. Beckett and White (1964), used the quantity (Q) and intensity (I) relation as a measure of soil PBC, where dQ/dI = PBC. The Q parameter, represents the amount of P in reserve, bound to the labile pool in the soil. This parameter can be measured, for example, by chemical extraction or by isotopic exchange, among other methods. The I parameter, is the chemical potential of orthophosphate, or phosphate activity in the soil. It can be estimated by measuring the P concentration in a solution that has been equilibrated with the soil for a determined amount of time (Beckett and White, 1964). These authors have reported a strong linear relationship between Q and I for several soils. This suggests that a given soil has a unique PBC value regardless of the value for Q or I, and the PBC differs between different soils. However, the authors did not report any data on the effects of initial soil P status on soil PBC neither what soil property/properties determines or controls the PBC. Other authors have used different mechanisms to estimate soil PBC. For example, Ransome (1988) calculated PBC by applying increasing amounts of P to several soils. After a certain equilibration time *t*, STP was determined and regressed on the P application rates used in the study. The PBC value was then calculated by taking the reciprocal of the slope of that regression line as follows:

$$PBC = \frac{1}{\alpha}, \text{ where } \alpha = \left(\frac{\partial STP}{\partial PA}\right)_{\text{sp}}, \text{ therefore } PBC = \left(\frac{\partial PA}{\partial STP}\right)_{\text{sp}} \qquad [1]$$

where α is the slope of the line that describes the increase in STP as a function of P application rate (PA). The partial derivative indicates that the source of P (sp) is being held constant and rate is the only variable allowed to change. Figure 1 shows this relationship for a hypothetical soil, though it was generated from real data. Researchers have reported PBC values ranging from 1 to more than 8 for various soils (Griffin et al., 2003; Laboski and Lamb, 2003). However, little is understood about what soil property/properties regulates the soil PBC.

The second concept regards the sorption maximum and sorption strength and those properties are related to how much P can adsorb onto soil particles (sorption maximum) and how strong (sorption strength) the chemical bond between the soil particles and the P is. The sorption maximum and sorption strength of soils are calculated by isotherm experiments. Isotherm experiments are performed by equilibrating a given amount of soil with solutions of increasing P concentrations and then determining the amount of P left in the solution after equilibrium is attained. The amount of P left in solution after equilibrium is strongly related to the amount of P initially in solution. Figure 2 shows this relationship for a hypothetical soil, though it was generated from real data. Depending on the soil type the sorption maximum can range from 100 to 1,000 ppm, whereas the sorption strength can range from 0.1 to 0.7 (Laboski and Lamb 2004; Sidique and Robinson, 2003). The higher the value for the sorption maximum is the more P can be held in the soil, and the higher the sorption strength the stronger the chemical bond between the particle and the P is.

The soil PBC and the sorption maximum and sorption strength are soil parameters that are well understood individually. However, there is no research that has shown how the two parameters are related. In addition, there is no research that has demonstrated what soil property/properties controls each parameter. Another gap in the scientific knowledge appears when the two properties are plotted on the same scale. For example, Figure 3 shows a theoretical plot where both parameters were plotted as a function of P added in ppm. The zone called "Unexplored region" represents an area in P adsorption/availability that has not been studied before. Understanding this "Unexplored region" is the key to making the connection between the soil PBC and sorption maximum and strength of soils. Because soil PBC relates what fraction of the applied P will bind to soil particles and the isotherm relates how much and how strong P can bind to soils, connecting the two could help improve P management in areas that might be potentially sensitive to P application. Furthermore, this could also lead to better P management in any land that receives P as inorganic fertilizer for crop production.

Objectives:

The objective of this research was to:

i) Determine the soil adsorption coefficients sorption maximum (*b*) and sorption strength (*k*) in the soils collected for the study.

Material and Methods:

Thirty-three soils samples were used in this study. Samples were collected from areas under agricultural use from different regions in the United States. There were 26 soils collected from MN, three from Texas, one from Iowa, and three from Wisconsin. Table 1 lists the soils and PBC values of each soil as determined using the Bray-1, Olsen, Mehlich-3 and water extracts.

After soil collection, soils were air dried and sieved through a 2-mm sieve to remove large size particles and stored in plastic buckets until needed to the study. The adsorption coefficients of each soil were determined using a 24 h soil solution mixing study. In the study, a subsample of each soil (1 gram) was mixed with increasing amounts of fertilizer P (0 to 12000 mg P kg^{-1}) and agitated at 25°C for 24 h (time required for equilibrium between fertilizer P and soil). After the 24 h reaction time, the samples were centrifuged and the solution was separated from the soil. The solutions were then analyzed using inductively couples plasma optical emission spectrometry (ICP-OES).

Results

Figure 1 shows the response observed in the P adsorption as a function of P concentration in the solution. The results of this study show two distinct behavior. One behavior is well known and is the behavior we were attempting to better understand and is the behavior that takes place from 0 to about 100 mg P L^{-1}. For P concentration above the 100 mg P L^{-1}, a second unexpected behavior takes place. We are not yet sure why this second behavior is happening but it has never been reported in the literature before. It appears that there is a change in phase controlling P adsorption in soils when the P concentration reaches a limit value. Further studies will be needed to fully understand this behavior.

The results observed for the first behavior, however, are well within the expected range and also is very similar to the results reported in the literature for soils with similar properties (Laboski and Lamb, 2004). Table 1 has the adsorption coefficients for selected soils and were developed for P concentrations up to 100 mg P L^{-1}. Coefficients for the full range in P concentration will only be possible after new mathematical equations are developed.

In the next phase of the study we will start to combine the results observed in the first study, the one where we develop PBC curves, with the results from this study. The correlations will help us make to provide a complete understanding of the soil properties that control the behavior of P in soils.

Financial Report

Expense	**Budgeted**	**Expenses**	**Remaining**
Salary	$21,080	$21,080	$0.00
Laboratory Supplies	$2,782	$2,782	$0.00
General Operations Services	$0	$0	$0
General Operations Supplies	$0	$0	$0
Travel	$4,638	$4,638	$0
Total	$28,500.00	$28,500.00	$0.00

References

Beckett, P.H.T., and R.E. White. 1964. Studies on the phosphate potentials of soils. part III: The pool of labile inorganic phosphate. Plant and Soil 21:253-281.

Griffin, T.S., C.W. Honeycutt, and Z. He. 2003. Changes in soil phosphorus from manure application. Soil Sci. Soc. Am. J. 67:645-653.

Laboski, C.A.M., and J.A. Lamb. 2003. Changes in soil test phosphorus concentration after application of manure or fertilizer. Soil Sci. Soc. Am. J. 67:544-554.

Laboski, C.A.M. and J.A. Lamb. 2004. Impact of manure application on soil phosphorus sorption characteristics and subsequent water quality implications. Soil Sci. 169:440-448.

Siddique, M.T., and J.S. Robinson. 2003. Phosphorus sorption and availability in soils amended with animal manures and sewage sludge. J. Environ. Qual. 32:1114-1121.

Table 1. Adsorption coefficients for selected soils used in the adsorption curve study.

Soil	k	S (mg P kg^{-1})
Clarion	0.099	348
Codova	0.112	389
Esthervile	0.114	299
Fargo	0.086	339
Gunclub	0.057	454
Hubbard	0.152	238
Nicollet	0.149	369
Normania	0.090	507
Sorden	0.074	352
Ves	0.171	392
Waukegan	0.037	545
Wheateville	0.074	451
Zimmerman	0.276	168

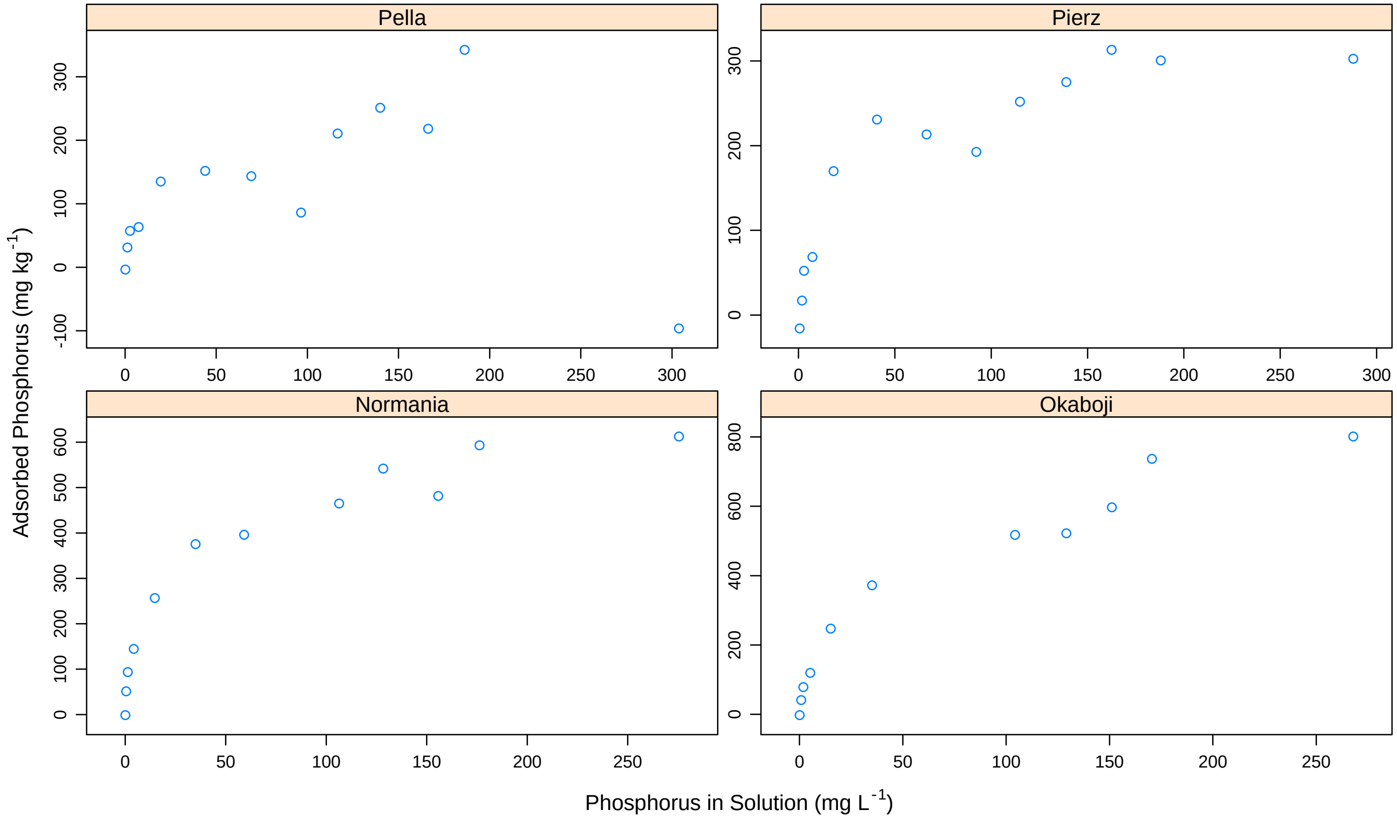

Figure 1. Phosphorus adsorption as a function of phosphorus concentration in the solution for the Pella, Piera, Normania, and Okaboji soil series.