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MODELLING PHOSPHORUS INPUTS FOR CERRADO CROPPING SYSTEMS

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Introduction

The objective of a soil test interpretation is to be able to recommend the optimum rate of fertilizer application. One philosophy of achieving this is to maintain a nutrient so that its extractable concentration is at a level sufficient for maximum yield. In order to compute the optimum rate of a given nutrient, three values are required: (i) existing extractable nutrient concentration in the soil, (ii) the concentration sufficient for a maximum yield, and (iii) a buffer capacity factor indicating the change in soil nutrient concentration during a period per unit of nutrient applied. With the inclusion of economic considerations, the interpretation may be modified to recommend the rate of fertilizer required to maximize net returns.

The levels of extractable P sufficient for maximum yield vary with soil properties (Lins et al., 1985). Extractable P alone, however, may not provide adequate information on the critical concentration of nutrients for predicting fertilizer recommendations. Other factors, for example, clay content have been shown to be correlated with P adsorption capacity (Olsen and Watanabe, 1963) and with P buffering capacity of soils (Ozanne and Shaw, 1968). Phosphorus sorption is also influenced by the type of clay minerals in soils (Karim and Adams, 1984). Lins et al (1987) showed improved prediction of P requirements for soybean when clay content, Mehlich-1, Mehlich-3, Bray-1 and an ion exchange resin extractable P were used.

The objectives of this paper is to present models generated with four different methods of extractable soil P, combined with clay content to predict the optimum P fertilizer rate for soybeans in the Cerrado region of Brazil.

Material and methods

Experimental procedures. The experimental procedures involved in this study, to generate data to feed the developed model, were carried out under greenhouse, laboratory and field conditions. Details of all procedures, were previously reported by Lins and Cox (1989a) and Lins and Cox (1989b). Seven soils were used under both, greenhouse and field conditions. However, data of two out of the seven field sites were used to validate the model.

Inputs necessary to construct the model. The mathematical approach used to generate the present model can be applicable for a particular group of soils located anywhere. However, to build-up this

model, the ideal situation would be to have long-term P experiments located within the area of interest. From these experiments, data relative to yield, extractable soil-P, and clay content or other soil properties that reflect soil P buffering capacity are necessary as the input for the model whose objective would be to predict the most economical-P fertilizer rate for crops to be grown in areas where the long P studies were located.

Mathematical approach

A descriptive model to express extractable P level (X) following fertilization (F) with time (T) was developed by Cox et al. (1981), this model was as follows:

$$X = X_{eq} + [(X_0 + b_1F + b_2F^2) - X_{eq}]\ e^{(-KT)} \qquad (1)$$

Where X_{eq} is an equlibrium soil test obtained from the check plots of long term P experiments; X_0 is the extractable soil P before P fertilization in kg ha^{-1}; b_1 and b_2 are linear and quadratic coefficients of the regression equation and express the soil P buffering capacity, K is constant for loss that P fertilizer undergoes with time after its application in the soil. Basically, this model is an integration of two equations. One expresses the change in initial extractable nutrient level (X_{init}) with time which is related to K as follows:

$$X = X_{init}\ e^{(-KT)} \qquad (2)$$

Upon addition of P fertilizer, it is assumed that there are several reactions that occur which differ markedly in rate. We limited our consideration to two groups; an initial, very rapid adsorption expressed by b_1 and b_2 coefficients in Eq. 1, and a slower reaction which follows, probably precipitation, expressed by the loss constant (K) in eq. 1 and 2. Data is often available in which several rates of fertilizer have been applied to establish successively higher soil levels of a nutrient, followed by observations made for a period of years with no further fertilization. With such data, the value of X_{init} and K at each level of fertilization may be preliminarily estimated by Eq. 2.

Preliminary estimates of b_1 and b_2 (Eq. 1) are determined after obtaining the estimated values of X_{init} for each P rate as described above using Eq. 2. The X_{init} values are regressed as a function of F, the rate of fertilization in kg ha^{-1}. If several estimated values of X_{init} are available, it may be determined if the relationship between X_{init} and F is linear or quadratic. The regression coefficients obtained give the preliminary estimates for b_1 and b_2 in Eq. 1. The preliminary estimates of K were obtained by Eq. 2 for each P rate applied to each soil; then they were averaged.

Once the final estimates of b_1, b_2 and K are obtained for a certain soil, solution of Eq. 1 gives the extractable soil P concentration that one could expect to obtain from that particular soil a certain time after a single P fertilizer application.

The descriptive model developed by Cox et al. (1981) allows one to determine the immediate effect of fertilizer rate, F, on extractable soil P concentration for only one initial soil test level X_0. This expression was modified by Lins et al. (1985) in order to allow this model (Eq. 1) to

consider other initial soil P concentrations.

Taking into account economic considerations, net income (N) was calculated by computing crop income minus fertilizer cost. Crop income was the yield times the soybean price (Q) and the fertilizer cost was the rate (F) times the fertilizer cost (S).

$$N = QY - SF \quad (3)$$

Combining these approaches gave fertilizer rates for maximum net income for different given soil test levels for sites used in this study. This was done with the data from each site for six initial levels between X_0 and greater values up to where the effect of fertilizer rate became negligible. The predicted fertilizer rates obtained for the five soils were then evaluated by multiple regression so that the fertilizer for maximum net income (R) was a function of initial soil test level (soil P) and other selected soil properties. This expression included the main effect interation term. For example, if soil P and clay are considered, the equation became:

$$R = a+b\ (\text{soil P}) + c\ (\text{clay}) + d\ (\text{soil P})\ (\text{clay}) \quad (4)$$

With this expression, the fertilizer P rate for maximum income becomes a continuous function of initial soil test level and clay content. In some cases, quadratic terms were also used.

Results and discussion

For the purpose of this paper, only data from the field studies will be presented and discussed. Data obtained in greenhouse experiments were previously reported (Lins and Cox 1989a). The soils from the five long term study sites were initially very low in extractable P, ranging from 0.6 to 6.0 g m^{-3} among the four extractants (Table 1). The soil with the least clay content (12%) had the highest native extractable P level. This would be expected from its characteristics of low P adsorption maximum and low surface area (Table 2).

Average maximum yield is estimated by the coefficient "A" in Table 3. The yield response per unit of soil P extracted with M1P, M3P and B1P was greater with increasing clay content, as indicated by the larger value of the coefficient "C" in Table 3. This means that a selected yield, such as 90% of the maximum, would be reached at a much lower soil P level as the clay content increases. The higher requirement on sandy soils is probably due to lower diffusion rate and buffering capacity. The diffusion rate of P is less in sandy than in clayey soils (Olsen and Wantanabe, 1963).

The immediate residual effect of P fertilization estimated as extractable soil P increases as clay content decreases. These effects were similar for M3P and B1P extractants and indicated about 15% immediate recovery for the soils with around 60% clay, increasing to over 50% immediate recovery for the soil with only 12% clay. Here, it becomes important to point out that when Mehlich-1 extractable P was used a quadratic relationship between applied P and soil P recovered just after application and rototilling was observed. However, when the other soil P extractants were used, this relationship was linear. That is the reason why in Table 3 the b_2 term appears only for the Mehlich-1 extractable soil P.

Table 1. Selected chemical properties of the soil prior to treatment

Clay	pH	Al	Ca + Mg	K	Extractant			
					M1P[2]	M3P[3]	B1P[4]	Resin[5]
%	1:2.5	Cmol L^{-1}			g m^{-3}			
68	5.0	0.63	0.32	0.07	0.6	1.5	1.5	2.1
63	4.9	1.12	0.68	0.10	1.7	2.6	2.4	6.0
57	4.8	1.30	0.36	0.07	1.6	1.6	1.9	3.4
27	4.6	1.26	0.95	0.12	3.9	4.7	4.6	5.7
27[1]	5.0	1.10	0.84	0.13	1.1	1.8	1.9	2.3
21[1]	5.7	0.30	0.34	0.07	0.6	1.7	2.3	2.8
12	5.2	0.34	1.04	0.09	5.0	5.9	6.0	5.0

[1]Soils used to validate the proposed model
[2]Mehlich - 1 extractable soil P
[3]Mehlich - 3 extractable soil P
[4]Bray - 1 extractable soil P
[5]Ion exchange resins extractable soil P

Table 2. Surface area, mineralogical composition and P adsorption maximum of soils from the five long - term P studies

Clay	Surface	Gibbsite	Goethite	Kaolinite	Hydroxy Interlayered Vermiculite	Free Iron Oxides	P Adsorp-tion Maximum
%	m^2 g^{-1}	% in soil					mg g^{-1}
68	35.4	44.2	3.4	20.4	0.0	2.7	0.7039
63	32.1	12.6	14.5	28.4	7.6	12.8	0.6643
57	30.8	6.7	7.2	28.8	5.3	6.2	0.6450
27	11.6	0.5	3.0	20.3	3.2	5.1	0.4246
12	6.8	0.1	2.3	7.8	1.8	2.0	0.1462

The amount of fertilizer P recovered immediately by the resin extractant was not the same as that for the other extractants; more P was recovered from the clayey soils and slightly less from the more sandy ones (Table 3). The results from the resin extractant, therefore, should estimate plant uptake better than those from M1P, M3P and B1P extractants. The relationship between rate of decrease of resin P over time expressed by the coefficient "K", was opposite that noted with M1P, M3P and B1P extractants, but the reason for this reversal is not clear.

Table 3. Coefficients or parameters for yield response and residual P equations for four extractants for soybeans grown in the field on five soils differing in clay content

Coefficient or Parameter	Clay (%)				
	68	63	57	27	12
For M1P					
Xeq	1.04	1.60	2.50	2.96	5.62
Xo	1.20	3.70	3.34	7.80	10.00
b_1	0.0413	0.0996	0.0479	0.2624	0.3136
b_2	0.00079	0.00014	0.00031	0.00028	0.00066
K	0.2493	0.3083	0.2493	0.2596	0.2463
M3P					
Xeq	2.70	2.20	2.60	4.20	6.50
Xo	3.00	5.30	3.20	9.00	11.80
b	0.1312	0.1586	0.1635	0.3466	0.5374
K	0.2118	0.1978	0.2135	0.1193	0.1475
For B1P					
Xeq	2.40	2.60	3.14	6.90	7.50
Xo	3.00	4.80	3.80	9.20	12.00
b	0.1475	0.1924	0.2003	0.4283	0.5328
K	0.2199	0.1954	0.2279	0.2048	0.1444
For Resin					
Xeq	3.42	6.78	3.84	6.22	5.53
Xo	4.20	12.00	6.80	11.40	10.00
b	0.2089	0.2920	0.2598	0.3702	0.4793
K	0.1770	0.2011	0.1984	0.2666	0.2728

Model application

When the optimum P fertilizer rate was predicted with extractable P alone, 66, 67, 57 and 62% of the variation was accounted for with M1P, M3P, B1P and Resin extractants. However, when the clay-squared term was introduced in a multiple regression analysis, 86, 84 and 83% of the variation was accounted for, respectively, with Mehlich-1, Mehlich-3 and

Bray-1 extractants. With the resin, the clay term did not need to be squared and this soil P extractant combined with % clay accounted for 95% of the variation in the optimum P rate. This may be due to the ability of this extractant to extract more labile P than the others.

Besides clay content, surface area, P adsorption maximum and gibbsite content in soils were the three best soil properties to be combined with extractable soil P to predict the optimum P fertilizer rate using this model. Since clay content can be estimated readily it was selected as the factor that should be included when predicting P fertilizer requirement. The relationship found for M1P was:

$$R = 95.6 - 3.14\ (M1P) + 0.0046\ (clay)^2 - 0.0012\ (M1P)\ (clay)^2$$

where the predicted fertilizer P rate R, and M1P are in kg ha^{-1}.

The relationship found for M3P is similar to that described for M1P and can be described as follows:

$$R = 60.0 - 0.38\ (M3P) + 0.012\ (clay)^2 - 0.0015\ (M3P)\ (clay)^2$$

Equations to predict optimum P fertilizer rates were also developed for the B1P and resin extractants. They are:

$$R = 62.4 - 0.64\ (B1P) + 0.011\ (clay)^2 - 0.0011\ (B1P)\ (clay)^2$$

$$R = 31.6 + 0.0742\ (resin\text{-}P) + 1.49\ (clay) - 0.0624\ (resin\text{-}P)\ (clay)$$

The equation for B1P is quite similar to that of M3P, as would be expected from the composition of these extractants. The function for resin-P differs in two respect from the other extractants. First, the coefficient of resin-P is positive, indicating more fertilizer would be recommended as soil P increases. Second, the clay term in the resin-P equation also is a direct effect rather than a squared term as in the other equations.

Model validation

In the two validation studies, maximum soybean grain yields were between 2.600 and 3.100 kg ha^{-1}. The yield response was calculated as a function of fertilizer P and solved at 90% maximum yield. The results showed that 90 and 200 kg ha^{-1} should have been applied on the soils with 27 and 21% clay, respectively. When 27% clay and the P in that soil by Mehlich-1 were used the predicted P rate was 91 kg ha^{-1}. Thus the M1P model was validated for this particular soil. For this same soil, using equations 6, 7 and 8, the P rate is somewhat less, about 70 kg ha^{-1}. This is a fairly reasonable estimate considering that the initial soil P level is extremely low, about 2 g m^{-3}.

For the soil with 21% clay, however, the prediction was only about 1/3 of the required 200 kg P ha^{-1}. This soil had an atypically high amount of gibbsite which may account for the unusually high P rate required. If so, applications of these equations, to soils with low clay contents, should be restricted to the more common, kaolinitic soils of this texture in the region.

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