

SHORT NON-REFEREED PAPER

FACTORS CONTROLLING THE SOLUBILITY OF PHOSPHORUS IN SOILS OF THE SOUTH AFRICAN SUGARCANE INDUSTRY

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Abstract

Management of phosphorus (P) for crop production requires the following considerations to be taken into account: (1) in their undisturbed state, soils on the eastern seaboard of South Africa are severely deficient in phosphorus; (2) P availability to crops is reduced through chemical immobilization (fixation); (3) P is the most costly of the macronutrients; and (4) 'overloading' of soil with P has environmental risks. In this study, the objective was to identify the primary factors controlling P solubility and immobilization in industry soils. Thirty-eight topsoils from irrigated and rainfed areas were subjected to detailed chemical analyses. Phosphorus immobilization was determined using sorption isotherms, single point immobilization indices and glasshouse incubations. Phosphorus solubility was poorly related to clay contents, and reasonably well-related to soil sample density and oxalate extractable iron (Fe); however, an outstanding feature of the results was the evidence of the major role of oxalate-extractable aluminium (Al) in controlling P solubility in all soils, regardless of their origin and properties. R² values for relationships between oxalate Al and isotherm slope, Bache and Williams phosphorus sorption index (PSI) and resin P requirement factor were 0.91, 0.90 and 0.86, respectively. The strong relationship between organic carbon (C) and oxalate-extractable Al (R² = 0.90) suggests that the bulk of the latter is complexed with the organic matter. Phosphorus immobilization in soils with >3% C was found to be four- to six-fold higher than in soils with lower C levels. The findings presented contribute to an understanding of P fixation mechanisms in industry soils, and provide an explanation for the recurring P requirement observed on higher organic matter soils.

Keywords: phosphorus, immobilization, oxalate Al, organic C, sorption isotherms

Introduction

In their undisturbed state, most southern African soils are severely deficient in phosphorus (P), and cropping systems require supplemental phosphorus to maximize their yield potential. When added fertilizer or manure phosphorus comes into contact with the soil, however, P solubility is reduced by adsorption reactions on the surfaces of soil colloids, and also by precipitation with other elements in the soil. The rates and intensity of these reactions are dependent on a range of soil conditions, including pH, clay and organic matter contents, and mineralogy (Arai and Sparks, 2007). In addition to adsorption reactions, in acidic soils (pH <5.5), P reacts mainly with aluminium (Al) and iron (Fe) to form insoluble compounds, the solubility of which increases with increasing soil pH. In alkaline soils, calcium (Ca) reacts with soluble P to form sparingly-soluble Ca-P minerals, the solubility of which decrease with increasing soil pH.

A better understanding of P dynamics in the soil is important for optimising P management. In particular, there is a need for soil testing services to provide reliable information on the likely extent of P fixation in samples submitted by growers. In this paper, we aim to identify the

primary factors controlling P solubility in industry soils, and thereby provide a basis for the development of a P fixation index for use in the routine testing of southern African sugar industry soils.

Materials and Methods

Thirty-eight topsoil (0-200 mm) samples were taken from fields located throughout the South African sugar industry. These soils ranged in clay content from 7 to 47% (mean = 27%), in organic carbon (automated combustion using LECO instrumentation) from 0.44 to 9.72% (2.22%) and in pH (CaCl₂) from 3.47 to 6.65 (5.06).

Ammonium oxalate extractable Fe and Al were determined by the method of McKeague *et al.* (1971). In the P fixation (sorption) investigation, two 'single-point' indices were compared: the Reeve and Sumner (1970) Bray II (0.02 N NH₄F + 0.02 N HCl) P desorption index (PDI) (overnight equilibration with a 200 mg P/L solution), and the Bache and Williams (1971) P sorption index (PSI) (18 hrs equilibration with 75 mg P/L in 0.01 M CaCl₂). Phosphorus sorption isotherms were developed for all 38 soil samples by equilibrating soils overnight with solutions (0.01 M CaCl₂) containing varying amounts of P.

For the determination of P requirement factors (PRFs), 1.5 L samples of each soil were treated with three different levels of KH₂PO₄ (0, 50 and 100 mg P/L). Soils were brought to field capacity by adding distilled water and were incubated for six weeks in open containers. Re-wetting to field capacity took place every fortnight. Following incubation, soils were air-dried, milled (<1 mm) and tested for P using anion exchange resin strips (Ionics AR103QDP). Phosphorus requirement factor values were determined from the inverse of the slope of the regression of soil test P against applied P (slopes of all functions were linear or near-linear), and thus indicate the amount of P needed to raise the resin soil P test by 1 unit.

Results and Discussion

The linear correlation coefficients (*r*) between P sorption indices and selected soil properties that influence P immobilization are shown in Table 1. A salient feature of these data are the strong correlations (all >0.90) of both ammonium oxalate extractable Al and organic C with sorption isotherm slope, Bache PSI and resin PRF. Oxalate extractable Al is widely reported to be a reliable indicator of P fixation in soils, irrespective of their chemical and mineralogical properties (Singh and Gilkes, 1991; Bainbridge *et al.*, 1995). The correlation between total organic C and Alox (*r* = 0.95) suggests that the bulk of the latter is complexed within the organic matter. It is noteworthy that, in this study, soils with >3% C were found to be four- to six-fold higher in P immobilisation than soils with lower C levels (data not shown). The strong relationship ($R^2 = 0.86$) between oxalate Al and resin PRF is shown in Figure 1a.

With sample density being well-related to organic C (*r* = -0.86), the fairly strong relationship between sample density and P immobilization indexes was not surprising. However, clay was poorly correlated with P immobilization; this finding is at variance with the observations of Johnston *et al.* (1991) who reported that P sorption in a wide range of Natal soils was strongly related to clay content.

Eighty-four per cent of the studied soils fell in the PRF range of 5-15 kg P/ha per mg P/L (Figure 1b) and this result is largely comparable with the findings of Johnston *et al.* (1991) and Henry and Smith (2004).

Table 1: Linear correlation co-efficients relating P-sorption parameters with various soil properties (n=38).

Parameter	Isotherm slope	PSI	PDI	PRF _{Resin}	Sample density	Clay %	Carbon (%)	Al _{ox}
Isotherm slope	1.00							
PSI	0.90**	1.00						
PDI	-0.71**	-0.55**	1.00					
PRF _{Resin}	0.87**	0.87**	-0.65**	1.00				
Sample density	-0.81**	-0.71**	0.83**	-0.83**	1.00			
Clay %	0.26 ^{n.s}	0.13 ^{n.s}	-0.69**	0.22 ^{n.s}	-0.52**	1.00		
Carbon (%)	0.93**	0.90**	-0.68**	0.92**	-0.86**	0.27 ^{n.s}	1.00	
Al _{ox}	0.95**	0.95**	-0.61**	0.92**	-0.78**	0.13 ^{n.s}	0.95**	1.00
Fe _{ox}	0.70**	0.70**	-0.75**	0.75**	-0.76**	0.64**	0.71**	0.72**

Isotherm slope at 0.2 mg P/L; PSI = P sorption index; PDI = P desorption index; Al_{ox} = oxalate-extractable Al; Fe_{ox} = oxalate-extractable Fe; ** - significance at p = 0.01; * - significance at p = 0.05; n.s. – not significant

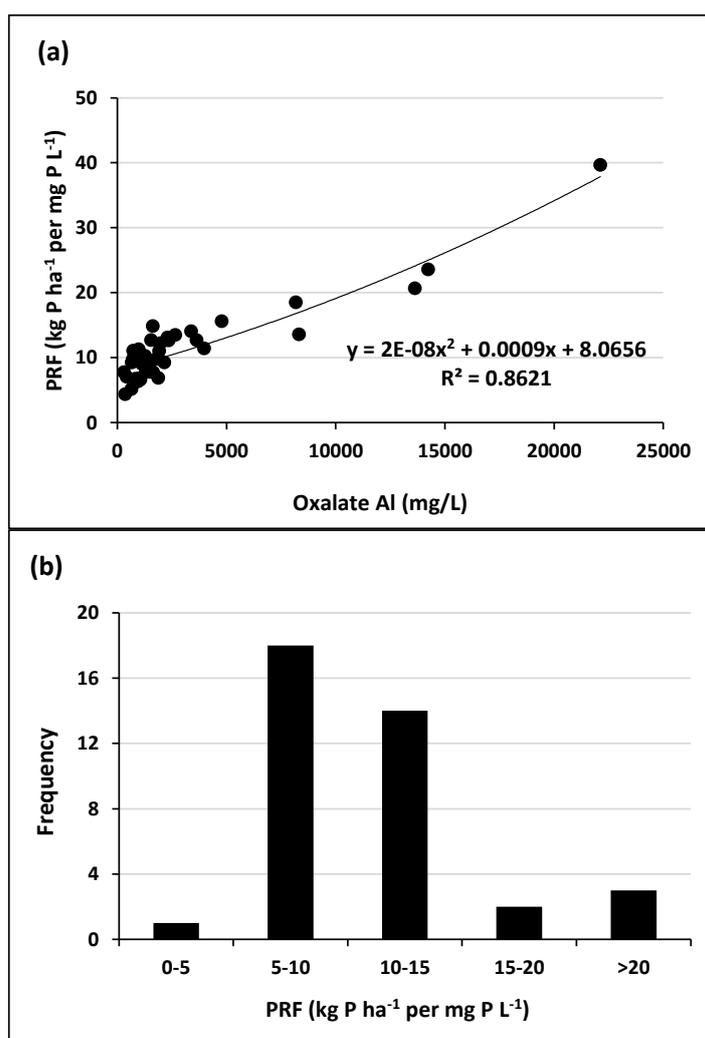


Figure 1: Relationship between PRF and oxalate-extractable Al (a) and number of soil samples at various ranges of PRF (b)

Conclusions

This study highlights the massive variations in P immobilization occurring in soils of the southern African sugar industries. Oxalate-Al and total organic C were found to be the main factors controlling P solubility in the soils studied. The fact that both of these properties are readily estimated using mid-infrared spectroscopy presents an opportunity for improving the efficiencies of fertiliser P use in the sugar industries.

REFERENCES

- Arai Y and Sparks DL (2007). Phosphate reaction dynamics in soils and soil components: A multi-scale approach. *Adv in Agron* 94: 136-174.
- Bache BW and Williams EG (1971). A phosphate sorption index for soils. *Journal of Soil Science* 22: 281-301.
- Bainbridge SH, Miles N and Praan R (1995). Phosphorus sorption in Natal soils. *S Afr J Plant Soil* 12: 59-64.
- Henry PC and Smith MF (2004). An improved phosphorus desorption index for the routine determination of the Ambic 2 phosphorus requirement factor of South African soils. *South African Journal of Plant and Soil* 21(1): 13-20.
- Johnston MA, Miles N. and Thibaud GR (1991). Quantities of phosphorus fertilizer required to raise the soil test value. *South African Journal of Plant and Soil* 8(1): 17-21.
- McKeague JA, Brydon JE and Miles N (1971). Differentiation of forms of extractable iron and aluminium in soils. *Soil Science Society of America* 35: 33-38.
- Reeve NG and Sumner ME (1970). Effects of aluminium toxicity and phosphorus fixation on crop growth on Oxisols in Natal. *Soil Science Society of America* 34: 263-267.
- Singh B and Gilkes RJ (1991). Phosphorus sorption in relation to soil properties for the major soil types of south-western Australia. *Aust J Soil Res* 29: 603-618.