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M S. Goundar
University of the South Pacific

R John Morrison
University of Wollongong, johnm@uow.edu.au

C Togamana
University of the South Pacific

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Keywords

Phosphorus, phosphorus buffer index, fertilizer recommendation, soil types

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Phosphorus Requirements of Some Selected Soil Types in the Fiji Sugarcane Belt

M.S. Goundar[1], R.J. Morrison[2*], C. Togamana[1]

[1] *School of Biological and Chemical Sciences, Faculty of Science, Technology and Environment,*
The University of the South Pacific, Private Mail Bag, Suva, Fiji.

[2] *School of Earth and Environmental Sciences, University of Wollongong, NSW 2522, Australia.*

* *Corresponding author. Tel.: +612 42214377. Email: johnm@uow.edu.au*

Abstract

The availability of phosphorus (P) in soil is perceived to be one of the limiting factors to sustainable sugarcane production in Fiji. The main objective of this research was to ascertain the amount of bioavailable phosphorus in some Fiji sugarcane growing area soils; this will be valuable in improving the determination of the required amount of inorganic fertilizer to be applied to the soil. In this study, twelve different soils were selected from the sugarcane belt of Fiji and phosphorus buffer index (PBI) and phosphorus isotherm experiments were performed. Soil physical and chemical parameters were also measured and Pearson's correlation tests used to identify patterns. It was found that Oxisols had the highest PBI values ranging from 134 to 170 while Inceptisols had the lowest ranging from 33 to 54. The PBI data followed a similar pattern to the generated isotherm curves of the different soil types. Most interest was in identifying soils with low PBIs as they have greater potential for P leaching through runoff into waterways. Clay content showed a strong positive correlation with PBI ($R = 0.76$, $p \leq 0.005$). There is strong association with phosphorus fixation in soil with increasing levels of Al and Fe in the soil. Phosphorus availability and P fixation varied with soil types.

Keywords: *Phosphorus, phosphorus buffer index, fertilizer recommendation, soil types*

1.0 Introduction

Phosphorus (P) is one of the critical nutrients required by sugarcane (*Saccharum officinarum*) for healthy growth. It is also an integral component of complex nucleic acids which play an important role in cell division and protein synthesis. A deficiency of P in plants causes stunted growth and leaf blades become slender. Apart from sustaining modern agriculture, there are many uses of P and high global demands have caused a decline in its availability and increase in cost (Gilbert, 2009; Bondre, 2011). It would therefore be beneficial to minimize the P fertilizer usage. The overuse of P fertilizer does not increase crop productivity substantially as only a certain percentage of applied fertilizer can be consumed by the crops, depending on the soil type, P fixing rates and other factors (Holford, 1997).

In general, many soils are deficient in phosphorus and regular application of fertilizer is required to sustain high levels of crop production in the agriculture sector (McLaughlin *et al*., 2011). Excessive application of fertilizers, however, may increase the P levels in agricultural soils above a threshold value where excess P begins to leach into the environment (Bundy and Sturgul, 2001; Djodjic *et al*., 2004; Somenahally *et al*., 2008; Coad *et al*., 2010). Soils have different capacities to retain phosphorus. The desired amount of phosphorus required for optimum crop production must be determined before being supplemented by addition of fertilizers (Gasparatos *et al*., 2006). Most Fiji soils are relatively old (Morrison et al, 1987) and are well leached due to Fiji's geographical position in the humic tropics; as such, Fiji soils have relatively low available plant nutrients including P (Daly and Wainiqolo, 1996).

Sugarcane production in Fiji commenced in 1880 and it remained the backbone of the Fiji economy until tourism took over at the turn of the 21st century. Cultivation of sugarcane in Fiji has been extended to steep sloping land characterized by infertile and highly weathered soils. As a result, the production of sugarcane has gradually declined since the late 1980s. This decline is due to several factors, but there is a clear correlation of decline in sugarcane production with fertilizer usage (Anon, 2010). A recent strategic action plan for improving sugar production in Fiji includes fertilizer as one of the immediate priorities (SCOF, 2012). A key element to this action plan is to identify recommended rates, application timing, and supply and delivery issues of fertilizers. The Sugar Research Institute of Fiji has completed extensive field trials to determine the fertilizer requirements of sugarcane crops in various sugarcane belt areas. The annual average phosphorus fertilizer usage for Lautoka, Rarawai, Labasa and Penang mill areas is 12.3, 12.5, 18.1, 14.8 kg ha^{-1} respectively (pers. comm. FSC, 2012). It is obvious that sugarcane production at Vanua Levu had the highest annual phosphorus fertilizer usage in kg ha^{-1} due to low phosphorus levels found in the soils (Morrison *et al*., 2005).

Previous studies on phosphate adsorption on Fiji soils have shown that significant quantities of added P are strongly adsorbed by soils, especially by the Al and Fe oxyhydroxide materials, and only limited quantities (10-30%) of fertilizer P are utilized by plants (Chee et al, 1978; Dandy and Morrison, 1980; Morrison et al, 2005). Although Singh (1982) made some preliminary studies, there has not been, however, any detailed study of the conditions under which fixed P becomes available over time to plants. Studies carried out by Halavatau (1989) and Singh (1982) showed sorbed P in soil will become available to plants after several years. Furthermore, Hansen *et al*. (2002) found the amount of phosphorus fertilizer applied in kg P ha^{-1} does not change the bioavailable P (mg kg^{-1}) in a (1:1) ratio due to P fixation processes which are dependent on the soil type, phosphorus fertilizer application rates and soil management history. In Fiji, there is need for sufficient data to develop appropriate fertilizer guidelines based on the soil properties, P solubility, rate of application and time of application in order to determine the required amount of fertilizer that would maintain optimum nutrient in soil.

This research project aimed at analyzing, interpreting and determining the phosphorus status of soils sampled from 12 different sites of the cane belt areas in Fiji. This research project involved measuring soil properties influencing P behavior, e.g., pH, % organic carbon, exchangeable bases, along with the available P and the phosphorus buffer index (PBI) which reflect the ability of soil to resist a change in its P concentration as P is removed by plant uptake or added in fertilizers or organic materials. Measuring the ability of the soils to hold onto P and determining the amount of P available for the plant uptake could assist in more appropriate recommendations for proper management of P-based fertilizers.

2.0 Materials and Methods

2.1 Soils

Composite soil samples were collected from three sugarcane farms in each sugarcane mill area (three in Viti Levu and one in Vanua Levu as shown in Figure 1 and Table 1). The sampling sites were selected on basis of providing samples from the different sugar growing soil types based on the USDA Soil Taxonomy (Soil Survey Staff, 1999). The soils studied belong to five soil orders as follows:

Inceptisols - soils with some diagnostic features, but no dominant characteristics,
Mollisols - fertile soils with a deep well structured, organic matter rich, base rich topsoil.
Alfisols - fertile base rich soils with a clay enriched subsoil (argillic horizon)
Oxisols - soil dominated by oxyhydroxides and kaolinite in the subsoil.
Ultisols - soils with low base saturation with clay accumulation in an argillic horizon.

Prior to sampling, a survey of each farm was carried out to determine soil homogeneity, and an area of approximately 0.2-0.3 ha was selected for the detailed study. Soil samples were collected using a spade from a depth of 0-20 cm using V transects across the area. Fifteen to twenty samples from two transects were combined and a 5.0 kg composite sub-sample for each soil was sent to the laboratory for analysis. The samples were air-dried and ground to pass through a 2 mm sieve (250 µm for carbon and nitrogen analyses). The analytical data reported represents the average of duplicate analyses of each composite. The quality control samples used were ASPAC Proficiency Programme samples which provided a means of maintaining confidence in the analytical standard methods used in the study.

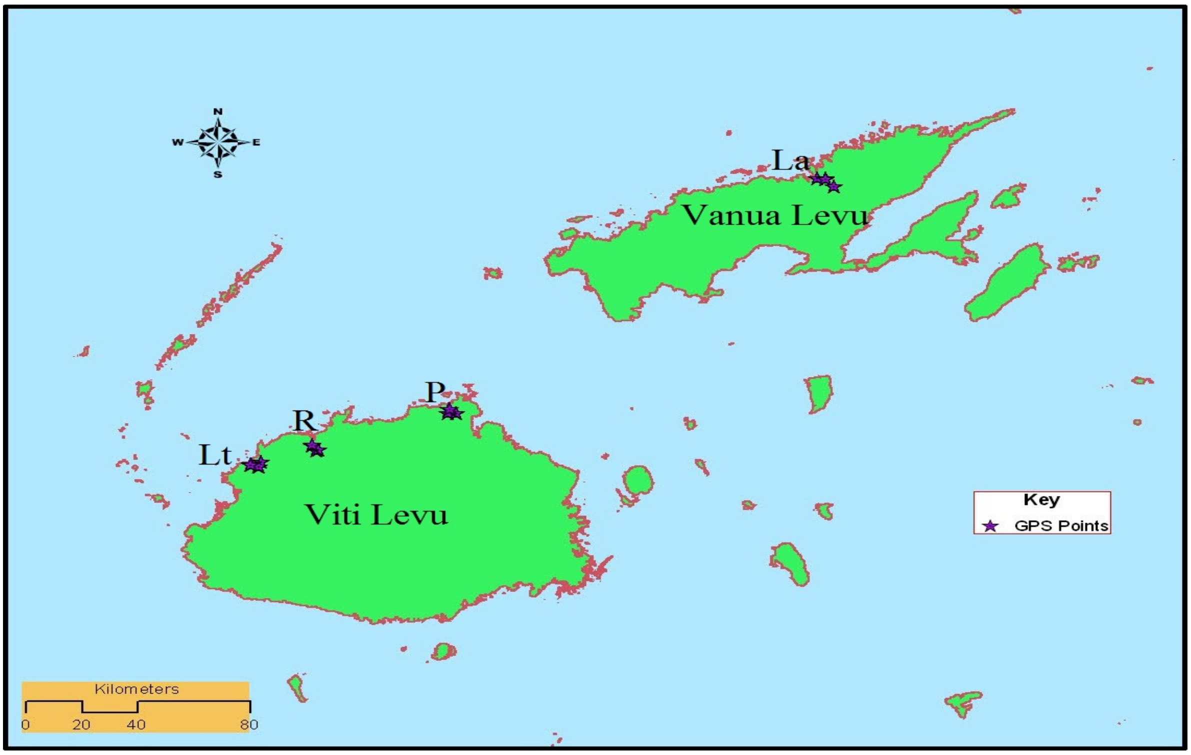

Figure 1. Map of Fiji Islands showing the sampling sites at four mill areas used for research (Lt = Lautoka, R = Rarawai, P = Penang & La = Labasa).

The soil orders were verified with the use of the GPS (Global positioning systems) and satellite images and maps of the farms were constructed using GIS (Geographic Information sSstems).

Table 1. Locations of Sampling Sites

Sugar Mill Area	**Sample No.**	**Farm No.**	**Soil Order***	**GPS Coordinates**
Lautoka	Lt 1 (1)	129	Alfisol	17°35'42"S, 177°30’50"E
	Lt 2 (2)	1222	Oxisol	17°52'15"S, 177°26’08"E
	Lt 3 (3)	291	Mollisol	17°54’54"S, 177°66’61"E
Rarawai (Ba)	R 1 (4)	1564	Mollisol	17°55'14"S, 177°70’19"E
	R 2 (5)	1512	Inceptisol	17°54’59"S, 177°71’32"E
	R 3 (6)	1407	Mollisol	17°53'29"S, 177°69’20"E
Penang (Rakiraki)	P 1 (7)	431	Mollisol	17°40’10"S, 178°14’58"E
	P 2 (8)	1342	Alfisol	17°40’04"S, 178°17’39"E
	P 3 (9)	1636	Inceptisol	17°38'24"S, 178°15’38"E
Labasa	La 1 (10)	618	Ultisol	16°25'02"S, 179°25’25"E
	La 2 (11)	7042	Oxisol	16°32'15"S, 179°31’58"E
	La 2 (12)	19116	Mollisol	16°24'41"S, 179°23’48"E

*Soil Survey Staff, 1999

2.2 Soil analysis

Soil pH was determined using the ASPAC method 3Al (Rayment and Higginson, 1992), organic carbon using the Walkley Black method (Walkley and Black, 1934), total N using the semi-micro Kjeldahl method (Blakemore *et al.*, 1987) and total P by Murphy & Riley (1962) using a colorimetric method as described in detail by Blakemore *et al.* (1987) and Daly *et al.* (1984), particle size analysis by the pipette method (Standards Association of N.Z., 1980) and method of Claydon (1989), oxalate-extractable Al and Fe as per ASPAC method 13A1 (Rayment and Higginson, 1992), exchangeable bases by ammonium acetate method using AAS following Daly *et al.* (1984) and Blakemore *et al.* (1987), extractable P by the modified Troug method (Gawander and Naidu, 1989) and phosphate sorption isotherm using the manual colorimetric procedure ASPAC 9J1 method (Rayment and Higginson, 1992). Moisture content was determined by drying a 10-20 g sample in the oven at 105° C overnight (Rayment and Higginson, 1992).

2.3 Phosphorus Buffer Index (PBI)

Soil analysis for PBI was carried out as per ASPAC method 9I2 extractions (Burkitt *et al.*, 2002) with Murphy and Riley analytical finish. PBI could be used to determine the P fertilizer requirements for increasing the extractable P levels (or Olsen extractable P level) to the appropriate critical level or adjust the critical levels for optimal crop production and estimate the potential for leaching of soluble P by runoff through the soil. PBI values were calculated without extractable P adjustments as PBI = $(Ps)/C^{0.41}$, where Ps is the amount of P adsorbed (mg P kg-^{1}) from a single addition of 1000 mg P kg^{-1}, and C is the resulting solution concentration (mg P L^{-1}). This method of measuring PBI is easier as there is no need to measure extractable P (Burkitt *et al.*, 2008).

3.0 Results and Discussion

Some important physical and chemical properties of soils under investigation in this study in relation to phosphorus sorption are given in Table 2.

Table 2. Physical and Chemical Properties of Soils in Fiji.

Soil	pH	PBI mean	Moisture Content (%)	Clay Content (%)	Organic Carbon (%)
Alfisols	6.0 ± 0.2	63 ± 1	29.9 ± 3.5	67 ± 7	1.9 ± 0.6
Inceptisols	6.1 ± 1.0	44 ± 15	29.9 ± 3.1	58 ± 4	2.0 ± 0.2
Mollisols	5.2 ± 0.4	83 ± 17	28.3 ± 1.8	61 ± 9	1.2 ± 0.2
Oxisols	5.0 ± 0.4	152 ± 25	28.7 ± 1.8	82 ± 2	1.6 ± 0.4
Ultisols	5.2	70	32	68	2.2

The results obtained from the PBI analyses indicate that different soils have different P sorption capacities. Therefore a common dosage of fertilizer applications will not meet the P requirements for different soils. These results showed that Oxisols had the highest mean PBI of 152 ± 25 which implies that P will be fixed strongly in Oxisols rendering it unavailable for plant uptake. Oxisols are expected to show a high affinity for P since they are dominated by oxyhydroxides and kaolinite in the subsoil. Similar findings were also reported by Syers *et al.*, (1971) for P fixation in highly weathered soils such as Oxisols and Ultisols. The result of this study also showed positive correlation between P fixation and Al and Fe content of soils ($R = 0.65$, $p = 0.04$) as shown in Figure 2. Mollisols have middle range PBI values and Inceptisols and Alfisols have the lowest values. Oxisols, Alfisols, Mollisols and Inceptisols from the four sampling locations showed wide range of PBI values and this is expected because each has different soil pH, soil texture, fertilizer application rates, chemical constituents, degree of weathering and vegetation which are known to affect the P sorption capacities of soils (Sims and Pierzynski, 2005).

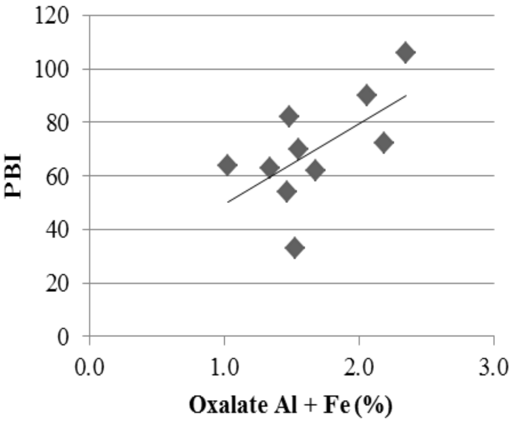

Figure 2. Relationship between PBI and % Oxalate Al + Fe.

3.1 Relationship between PBI, Clay content and Available P

The relationship of PBI and clay content of soils with regards to available P is given in Figure 3. There is a positive correlation between clay content of soil and PBI ($R = 0.76$, $p \leq 0.005$) as observed in previous studies (Burkitt *et al*., 2002; Cho-ruk and Morrison, 2004; Sharpley, 2000). The P fixation is strongly influenced by clay content of soil and is more specifically related to a large surface area for adsorption (Rayment and Higginson, 1992; Sims and Pierzynski, 2005; Rayment and Lyons, 2011; Guppy *et al*., 2005). Phosphorus retention will be minimal for soils containing higher percentage of silt and sand.

The particle size analysis data showed that all the soils studied have relatively high clay contents ranging from 54 - 84% (Table 2). In the present study, Inceptisols had the lowest clay content with the lowest PBI. In contrast, high PBI and high clay content are evident in Oxisols as these soils are commonly highly weathered soils and often clay rich (Syers et al, 1971).

The high amounts of Al and Fe oxyhydroxides in Oxisols and Ultisols soils are the reasons for high fixation of P resulting in lowering the plant available P (Tan, 2000). Soils with high PBIs have very low available P as fixation is high in soil. Figure 3 shows that Inceptisols had the lowest clay contents and PBI with relatively high available P. There is a large difference between available P in the two Inceptisols studied. The Inceptisols from Rarawai mill tended to show much lower available P compared to Penang mill and this may be due to differences in the soil pH (lower at Rarawai) and surface charge features as indicated by the cation exchange capacity (Goundar, 2013).

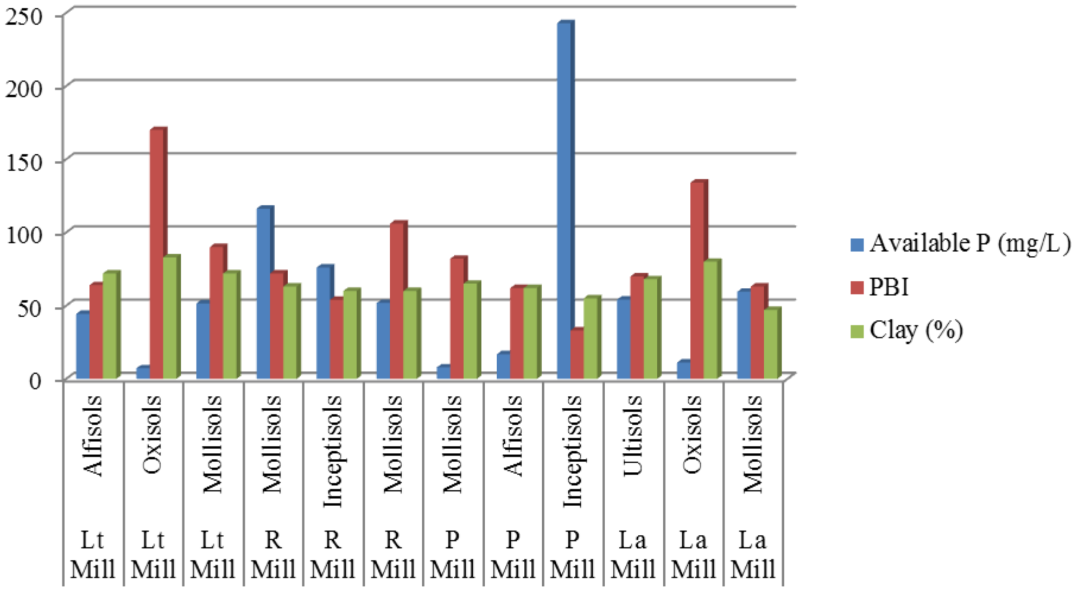

Figure 3. The trend of PBI of different soils with available P and clay (where Lt = Lautoka, R = Rarawai, P = Penang and La = Labasa).

The values for percent organic carbon in the topsoils (wt/wt) range from 1.46 to 3.09 as summarized in Table 2. The variations in organic carbon between different soils are likely due to differences in mineralogy and especially clay content (Spain et al, 1983). In this study, Ultisols have the highest organic carbon compared to the other soil types which is expected as Ultisols are often soils with substantial organic carbon. Generally, Oxisols have reasonable organic carbon contents (3-5%, Soil Survey Staff, 1999), but the two Oxisols analysed in this study have relatively low levels of organic carbon (1.8-2.4%) which is consistent with other work on sugarcane Oxisols in Fiji (Morrison et al, 2005). The notable decline in organic carbon in the sugarcane cultivated land could be due to the farming practices and tillage, which also has been reported by Morrison *et al*. (2005). Organic matter is a significant source of major nutrients for plant uptake (Spain et al, 1983)and the organic carbon of the soils can be improved; however, this depends on the management practices during sugarcane farming such as retaining trash.

The percent organic carbon analysed for the soils decreases in the following order: Ultisols > Inceptisols > Alfisols & Oxisols > Mollisols. Inceptisols are often characterized by organic rich topsoils (Naidu and Haynes, 1989); however, the Inceptisols studied here were found to have reasonable percentage of organic carbon (2.70 and 2.40) for the topsoils and lowest PBI of 33. Soil organic carbon has a slightly negative relationship with PBI as the organic carbon increases, the sorption P decreases indicating that the organic carbon competes with phosphate ions for binding sites (Sim and Pierzynski, 2005). Inceptisols also had the highest available P (242.9 mg kg^{-1}) due to lower fixation which is likely to be transported via surface runoff to waterways with high potential to trigger algal blooms (Sim and Pierzynski, 2005). The organic carbon contents of Alfisols are rather low in the range of 1.89 to 2.40% with comparable PBI values; however, this is not the only property that influences the availability of P in soils (others include pH, mineralogy (Sims and Pierzynski, 2005)). Organic carbon plays very important roles in soil and its application reduces P fixation in soil, maintains soil texture and also improves water holding capacity (Tan, 2000). As expected, the % organic carbon has a strong positive correlation with % nitrogen (R = 0.91, p = 0.000) suggesting that mineralization of organic matter is responsible for good levels of available nitrogen in soil.

3.2 PBI and Other Soil Properties

The tested soils had pHs ranging from 4.7 to 6.8 and pH varied with soil type. There were also variations in other soil parameters, such as, clay content, available P (Troug P), organic carbon, total nitrogen, total P, exchangeable bases, and oxalate Al + Fe. The available P and total P had a strong correlation (R = 0.85, P < 0.001) after exclusion of Inceptisols which had the highest available P, and lowest fixation capacity.

For data analysis, Pearson's correlation was performed showing that PBI has a moderate negative significant correlation with pH (R = -0.67, p = 0.017) as shown in Figure 4. The relation of PBI with available P showed a moderate negative relationship with R = -0.60 and p = 0.039 (Figure 5). Soil pH had a moderate positive correlation with available P (R = 0.63, p = 0.026). This indicates that the availability of P in soil is pH-dependent. Inceptisols (pH 6.8) had the lowest fixation as expected according the reviewed literature - fixation is minimal at pH 6.5. The results showed highest fixation of P at a very low pH of 4.7. This is similar to other studies, such as McBride (1994) and Guppy *et al* (2005), who found that P fixation in acid soils is mainly by oxyhydroxides of iron and aluminium because of the formation of very insoluble Al and Fe phosphates. In slightly acid to neutral soils available P increases, due to reduction of this fixation by aluminum, iron and manganese.

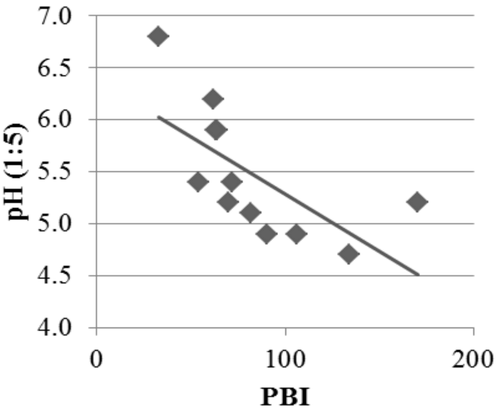

Figure 4. Relationship of PBI with pH R = -0.67, p = 0.017.

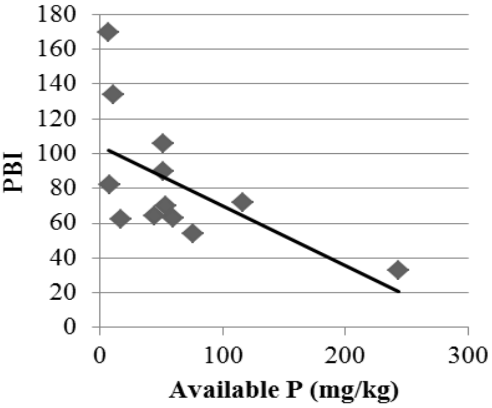

Figure 5. Relationship of PBI and Available P R = -0.60 and p = 0.039.

PBI has a good correlation with Fe_{ox} (R = 0.70, p = 0.02) but there was no clear relationship observed for PBI with Al_{ox}. Overall, PBI showed a moderate correlation (R = 0.65, p = 0.04) with $Al_{ox} + Fe_{ox}$ when correlation is performed after exclusion of the high values for Oxisols. The relationships of Al_{ox} and Fe_{ox} with P sorption capacity are well documented (e.g., Pant *et al*., 2002; Bruland and Richardson, 2004; Janardhanan and Daroub, 2010).

According to Weng *et al.* (2012), the factors which control fixation of phosphate to iron oxyhydroxides under normal soil conditions are pH, organic matter and Ca concentration.

PBI displayed a relatively strong negative correlation with exchangeable Ca (R = -0.79, p = 0.002, Figure 6) and PBI also with TEB (R = -0.76, p = 0.0039). PBI also displayed negative relationship with CEC as presented in Figure 7. It was also noted from the results that Oxisols with high PBI (170 and 134) had very low exchangeable calcium (2.00 and 4.86 cmol kg^{-1} respectively) compared to other soils indicating possible precipitation of calcium with phosphate. Inceptisols have the highest base saturation and exchangeable bases, available P, nitrogen and organic matter suggesting very fertile soils with a significant potential for nutrient loss to the environment.

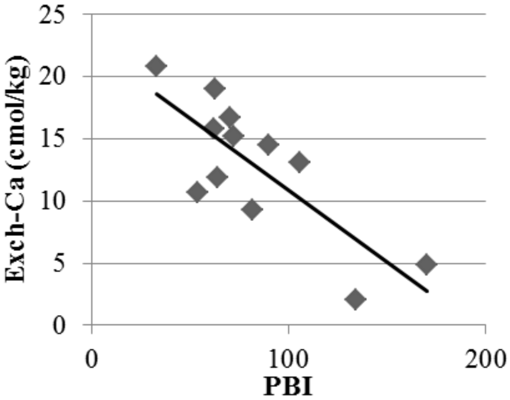

Figure 6. Relationship between PBI and Ca (R = -0.79, p = 0.002).

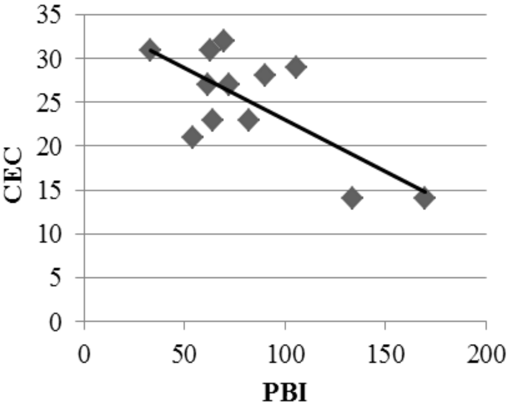

Figure 7. Relationship between PBI and CEC (R=-0.71 and p=0.009).

3.3 P Sorption Curves

The sorption curves obtained after various additions of P show the soils with highest sorption of P were Oxisols and the lowest sorbing P soils were Inceptisols. The low sorbing P soils have curves forming plateaux at low equilibrium concentrations whereas high sorbing soils have steeper curves (Figure 8). This means that Inceptisols with the lowest P fixation capacity and high available P may require less added P to reach saturation (threshold P concentration). In comparison, the soils with the lowest available P due to their high capacity to sorb P displayed curves higher than all other soil types. The PBI data compare well with the generated isotherm curves for the different soil types.

All soil types behave in a similar manner upon addition of P, the only difference is the relative positions of the curves which are dependent on the soil's capacity to sorb P before reaching the P adsorption maxima. It is apparent that increasing concentrations of P fertilizer will not directly increase the sorption of P in soil as soils have a certain capacity to sorb P (Bache and Williams, 1971; McDowell *et al.*, 2001). The soils analyzed in this research were previously supplied with P fertilizer; this addition of P has an effect on the position of the sorption curve for each soil. The Oxisol from the Lautoka mill area was sampled from ploughed and fallow land, and had the lowest soil test P value and the highest placed P isotherm, indicating, therefore, no recent fertilizer application. A soil with no fertilizer application or virgin soil moves the isotherm higher than one obtained after addition of P (Bache and Williams, 1971). The fertilized and unfertilized (virgin) soil maintains the same basic P sorption characteristics and only the position of the isotherm changes temporarily with increasing P fertilizer additions (Burkitt *et al.*, 2008; Bache and Williams, 1971). Burkitt *et al.* (2008) stated that continuous or single large applications of P fertilizers shift the sorption curves. Several studies have also shown changes in P sorption under normal farming practices after P fertilizer application (Barrow, 1974; Bolland and Baker, 1998).

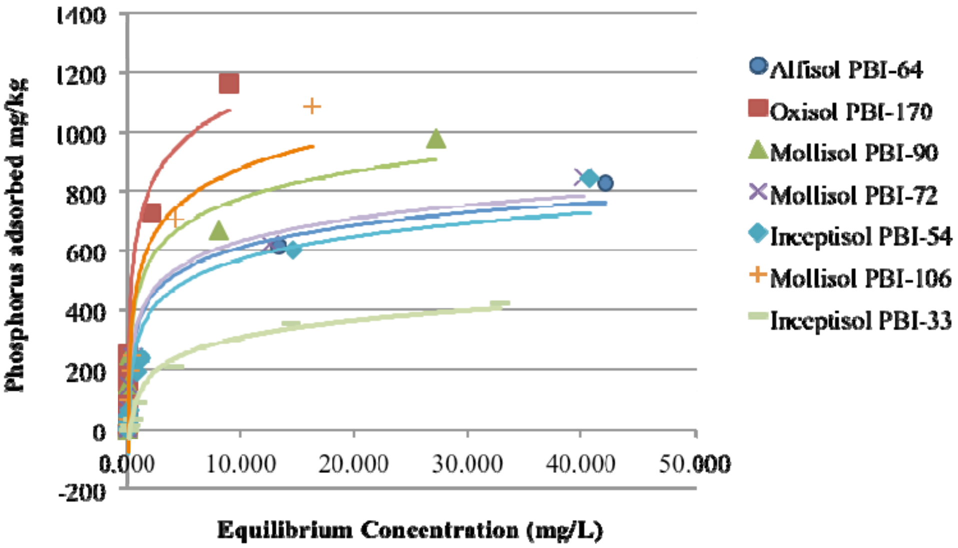

Figure 8. Sorption curves generated on different soils from soil isotherm experiments.

The soil with the highest PBI has the uppermost isotherm in Figure 8, confirming a high sorbing soil. This indicates that Oxisols are the highest P sorbing soils in this study, and will therefore require more P fertilizer to support plant growth. Inceptisols had the lowest buffer index value and are the low sorbing soils and will require the least amount of P fertilizer. In this sorption study, when the different soils were equilibrated with 0.01M $CaCl_2$ only, it was observed that there is release of P from soil particles through desorption reactions as identified in previous studies (e.g., Chee et al, 1978; Dandy and Morrison, 1980; Cho-Ruk and Morrison, 2004).

3.4 Equilibrium Phosphorus Concentration (EPC)

The individual isotherm curves for each soil type are plotted with the line of best fit equation used in calculation of EPC. The EPC values obtained in the isotherm experiments ranged from 0.006 to 0.224 mg L^{-1} (Table 3). Very low EPC values were generally obtained with the exception of soils which had high available P such as the Inceptisols of Penang Mill, and the Inceptisols and Mollisols of Rarawai Mill. EPC values had a very strong positive correlation with available P (R= 0.92, p = <0.01) while a negative relation is observed with PBI.

Table 3. EPC and equation of line of best fit P isotherms for the twelve different Fiji soils studied.

Mill Area	Soil Type	EPC (mg L^{-1})	Equation of Line of Best Fit
Lt Mill (1)	Alf	0.032	$y = 0.1066\ln(x) + 0.3674$
Lt Mill (2)	Oxi	0.019	$y = 0.1741\ln(x) + 0.6933$
Lt Mill (3)	Mol	0.026	$y = 0.1300\ln(x) + 0.4779$
R Mill (4)	Mol	0.033	$y = 0.1106\ln(x) + 0.3765$
R Mill (5)	Inc	0.058	$y = 0.1112\ln(x) + 0.3166$
R Mill (6)	Mol	0.034	$y = 0.1545\ln(x) + 0.5230$
P Mill (7)	Mol	0.003	$y = 0.0846\ln(x) + 0.4798$
P Mill (8)	Alf	0.017	$y = 0.0873\ln(x) + 0.3583$
P Mill (9)	Inc	0.224	$y = 0.0818\ln(x) + 0.1224$
La Mill (10)	Ult	0.034	$y = 0.0965\ln(x) + 0.3266$
La Mill (11)	Oxi	0.006	$y = 0.1013\ln(x) + 0.5210$
La Mill (12)	Mol	0.014	$y = 0.0893\ln(x) + 0.3793$

Conclusions

Phosphorus availability and P fixation varied with soil types. Soils with high P sorption capacities, such as, Oxisols will necessitate supplementing the soil with greater quantities of P fertilizer for optimum sugarcane growth as the soils have a lower quantity of available P. Sorption curves and PBI data were comparable, therefore PBI could be considered as a simple and effective test to predict P sorption of the different soils. The PBI testing of different soils also indicated which soils are likely to leach P. Inceptisols had PBI values as low as 33 indicating these soils have greatest potential for P leaching to the environment. Based on the PBI results, more accurate fertilizer recommendations can be developed, but more work is required in finalizing P fertilizer recommendations for optimum plant growth and reducing losses to the environment.

In addition, reducing the P losses to watercourses can be achieved by improving fertilizer recommendations, water infiltration through healthier soil structure, and the careful ploughing of top soil (Burkitt et al, 2011). Major losses of nutrients occur from the fields through runoff during the rainy season just after harvest and losses are generally lower during the growing period (Puustinen *et al.*, 2005) as fertilizer applied during rainy seasons gets washed away into rivers, lakes and oceans. Burkitt *et al.* (2011) noted that the runoff could be prevented by avoiding P fertilizer application on soil types which have satisfactory soil P levels and also if fertilizer is to be applied, it should be applied when the risk of surface runoff is low.

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