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Exploring the Nature of the Relationships Among Total, Extractable and Solution Phosphorus in Cultivated Organic Soils*

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Abstract: A study was conducted to find out the nature of the relationships among total P, extractable P and solution P under fertilized and unfertilized conditions for burned pineapple residues management practice in pineapple cultivation on tropical peat soils. There was no significant relationship among total P, extractable P and solution P for the unfertilized and fertilized conditions at 0-10, 10-25 and 25-45 cm depths. This revelation was partly due to low bulk density (due to the inherent nature of tropical peat soils) and leaching of P. To suggest some ways of reducing leaching, a more frequent P application (foliar or soil) schedule at lower application rates need to be studied, so that a response curve could be examined and optimum rates derived. This will help to address the issue of whether sufficient or excessive P is being applied in the right form and in a sustainable way.

Key words: Phosphorus fertilizers, pineapples, tropical peat soils, phosphorus leaching, soil total, extractable and solution P relationships

Introduction

Adequate supply of P for the entire growth period of plants is very important as the concentration of P in the soil solution must be maintained to a satisfactory level for plant growth and development. Phosphorus availability therefore, depends not only on its concentration in the soil solution at any given time but also on the ability of the soil to maintain the P concentration. As often experienced in the agricultural use of tropical peat soils, crop yield sharply declines with time after reclamation. As a result, high amounts of fertilizers are used to ensure continued crop production on these soils (Kyuma and Vijarnsorn, 1992). For example pineapple cultivation on peat in Malaysia is characterized by the application of 36 P ha^{-1} in the form of China rock phosphate per cropping cycle. This high application may be due to low mineral contents in the available forms (Andriesse, 1988; Okazaki and Yonebayashi, 1992; Yonebayashi *et al*., 1994; Funakawa *et al*., 1996) and low clay in tropical peat soils (Stevenson, 1994). Equally important investigation on how P concentration in solution relates the P-supplying ability in cultivated organic soils is lacking.

In their study to investigate the nutritional environment of natural or uncultivated tropical peat soils in Sarawak, Malaysia based on soil solution composition, Funakawa *et al*. (1996) observed that even though the concentration of P in the soil solution was high, the potential to supply P was not necessarily high, in spite of the apparent high intensity observed for the soil solution composition. Functional relationships between these phases have however not been explored for cultivated tropical peat soils where crop residues are burnt before replanting. This kind of investigation could

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be valuable to crop growers on organic soils because it may contribute to the development of efficient P management strategies. Additionally, it may help reduce the polluting effects from excessive P fertilizer applications since once P in the available form is depleted, replenishment from the solid phase may not be rapid enough to support the P requirement of plants if readily available input such as P fertilizer is not timely applied to the soil.

This study was carried out to investigate whether relationships could be established among soil total P, extractable P and solution P under fertilized and unfertilized conditions for *in situ* burning of pineapple residues management practice (the usual residue management practice before replanting) in pineapple cultivation on tropical peat soils.

Materials and Methods

The study was conducted on an Umbro Saprists peat soil at Peninsula Malaysia Pineapple Estate in Johor. The area has an annual precipitation of about 2000 mm. Mean monthly maximum and minimum temperatures are 31 and 23°C and relative humidity ranged from 70 to 90% per month. Two treatments were evaluated. Treatment 1 was *in situ* burning of pineapple residues (crowns, peduncles, leaves and stem) without fertilization (BWF) and treatment 2 was *in situ* burning of pineapple residues (crowns, peduncles, leaves and stem) with fertilization (BF). Each of the test plots was 4 m wide×12 m long (48 m^2). Three hundred suckers of cv. Gandul (the most commonly grown variety) suckers were planted in each of the test plots. The experimental plots were laid out in a randomized complete block design with four replications.

The normal P schedule of the pineapple estate was followed. Phosphorus was applied to the fertilized plots in the form of China phosphate rock (14%), at the total rate of 36 ha/P. At 83 days after planting, P was applied at 11 kg ha/P. Another 11 kg ha/P was applied at 144 days after planting. At 209 days after planting, 7 kg ha/P was applied. The same rate was also applied at 263 days after planting. The normal K and N schedule of the pineapple estate was also followed. All of the other plant management procedures and schedules of the estate were also followed.

To monitor the movement of P in the soil profile, peat soil samples were taken at the depths of 0-10, 10-25 and 25-45 cm. Before the start of the experiment, peat soil samples (4 core samples) were taken at these depths using a peat augur. The samples were analyzed for total P, extractable P and solution P. The extraction methods used to analyze these forms of P were the dry ash method (Cottenie, 1980), the double acid method (Van Lierop *et al*., 1980) and the squeeze methods (Bailey *et al*., 1996). The molybdate blue method was used for the P determination. The test plots did not significantly differ in their initial P forms (total, extractable and solution). Subsequent peat soil samplings were done 48, 83, 144, 263, 365, 417 and 446 days after planting. The samples were also analyzed for the three P forms mentioned using the above procedures. Prior to the commencement of the experiment, peat core samplers of 7.5 cm diameter were used to collect peat soil samples at the stated depths. Standard procedures were used to determine the bulk density of the experimental plots.

The statistical software used for these analyses was the Statistical Analysis System version 8.2 (SAS, 2001). It should be noted that the plot data were meaned before use in the statistical analyses.

Results and Discussion

The nature of the relationships among total P, extractable P and solution P at 0-10, 10-25 and 25-45 cm depths were explored. At 0-10 cm depth, trend analysis showed that there was no significant relationship between: (i) total P and Extractable P (Fig. 1), (ii) total P and solution P (Fig. 2) and (iii)

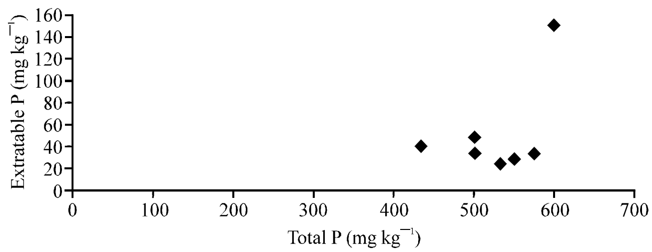

Fig. 1: Relationship between total P and extractable P at 0-10 cm for BWF

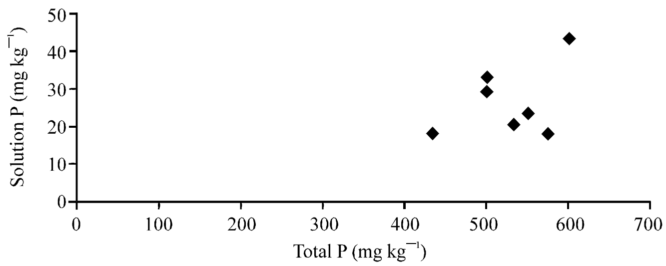

Fig. 2: Relationship between total P and soil solution P at 0-10 cm for BWF

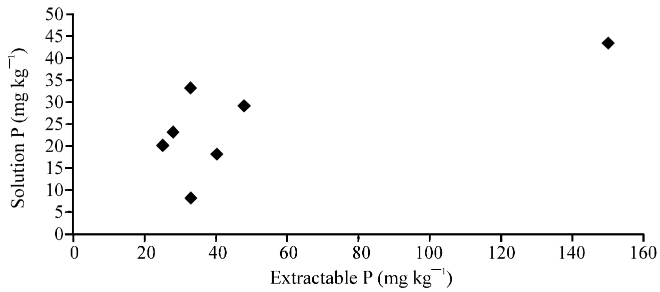

Fig. 3: Relationship between extractable P and soil solution P at 0-10 cm for BWF

extractable P and Solution P (Fig. 3) for the unfertilized plots (BWF). The un-relatedness among the three P forms can be seen further in Fig. 4. Whereas there was a general fluctuation of total P, the fluctuation of extractable P leveled off at 144 days after planting. In the case of solution P, it did not significantly change throughout the study compared to total P and extractable P (Fig. 4). At 0-10 cm depth, there was also no significant relationship among total P, extractable P and solution P for the fertilized plots (BF) as shown in Fig. 5 (total P and extractable P), Fig. 6 (total P and solution P) and Fig. 7 (extractable P and solution P). As presented in Fig. 8, the concentration of total P was relatively constant until 263 days after planting after which there occurred a sharp increase (due to fertilizations) till 365 days after planting. Afterwards, there was a sharp decrease of the total P until the end of the study. Comparing this pattern of total P to that of extractable P, the extractable P remained relatively unchanged until 144 days after planting after which there was also a sharp increase (due to fertilization) till 263 days after planting (Fig. 8). Unlike total P, the sharp decrease of extractable P occurred earlier (263 days after planting) and also leveled off earlier

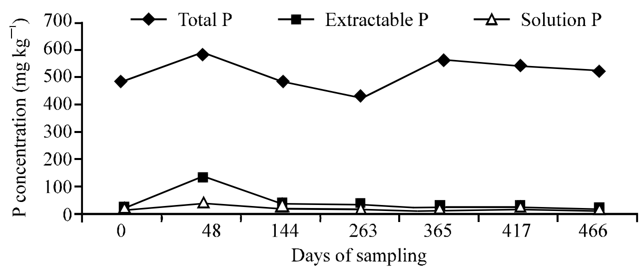

Fig. 4: Concentrations of total, extractable and solution P at different periods of sampling (0-10 cm depth) for BWF

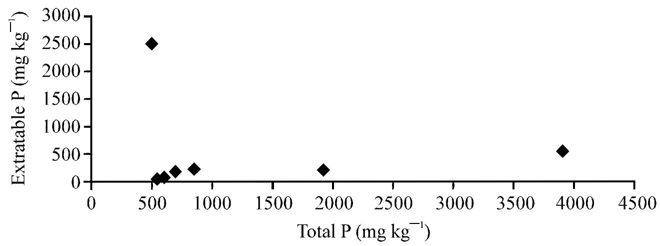

Fig. 5: Relationship between total P and extractable P at 0-10 cm for BF

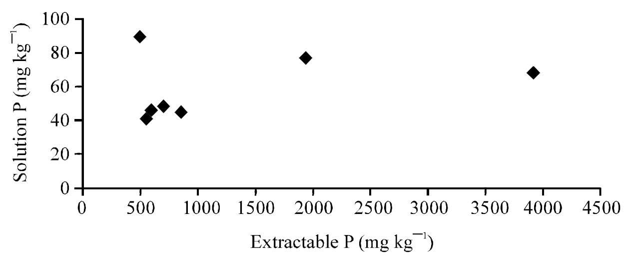

Fig. 6: Relationship between total P and soil solution P at 0-10 cm for BF

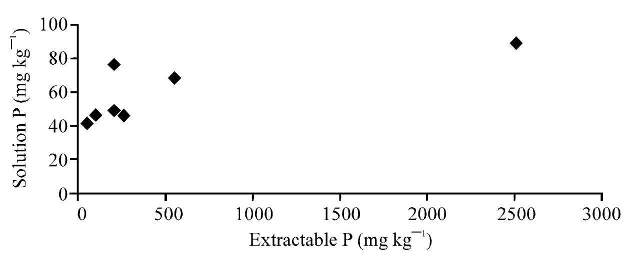

Fig. 7: Relationship between extractable P and soil solution P at 0-10 cm for BF

(417 days after planting) (Fig. 8). Unlike total P and extractable P, solution P remained almost constant throughout the study (Fig. 8). The general lack of phase of these three forms P at 0-10 cm partly explains the absence of quantitative relationships among them regardless of treatment.

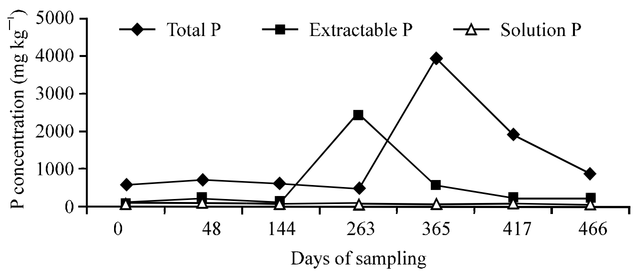

Fig. 8: Concentrations of total, extractable and solution P at different periods of sampling (0-10 cm depth) for BF

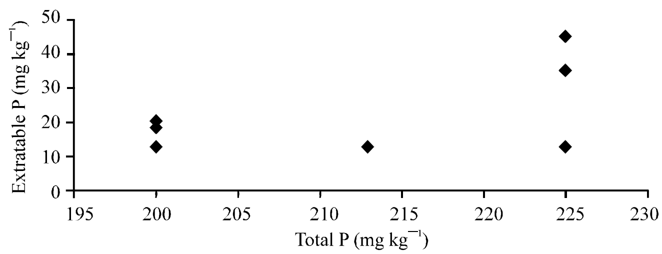

Fig. 9: Relationship between total P and extractable P at 10-25 cm for BWF

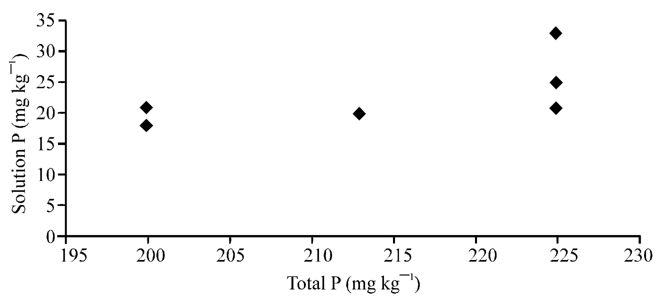

Fig. 10: Relationship between total P and soil solution P at 10-25 cm for BWF

At 10-25 cm soil depth, trend analysis revealed no significant relationship between: (i) total P and extractable P (Fig. 9), (ii) total P and solution P (Fig. 10) and (iii) extractable P and solution P (Fig. 11) for BWF. A similar observation was also made for BF at 10-25 cm (Fig. 12-14). This lack of this relationship can be seen in Fig. 15 (BWF) and Fig. 16 (BF) where the fluctuation of total P was obvious compared to those of extractable P and solution P (their concentrations were relatively not different throughout the study) in the unfertilized and fertilized plots.

At 25-45 cm soil depth, no significant relationship was found between: (i) total P and extractable P (Fig. 17), (ii) total P and solution P (Fig. 18) and (iii) extractable P and solution P (Fig. 19) for BWF. At this same depth, a similar observation was made for BF (Fig. 20-22). As presented in Fig. 23 (BWF) and Fig. 24 (BF), the fluctuation of total P was more pronounced compared to those of extractable P and solution (their concentrations were relatively not different throughout the study) in the unfertilized and fertilized plots.

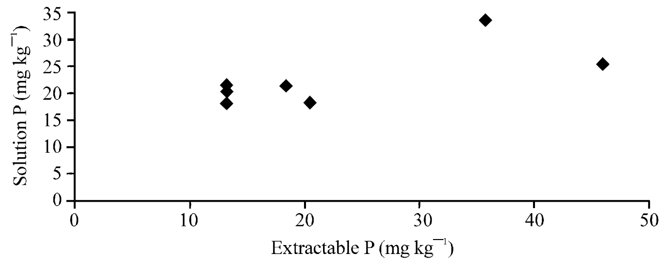

Fig. 11: Relationship between extractable P and soil solution P at 10-25 cm for BWF

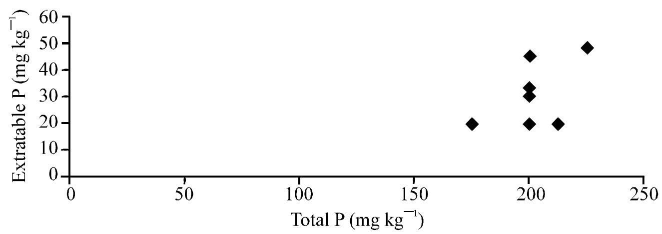

Fig. 12: Relationship between total P and extractable P at 10-25 cm for BF

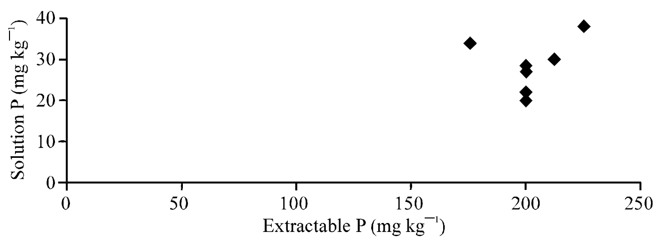

Fig. 13: Relationship between total P and soil solution P at 10-25 cm for BF

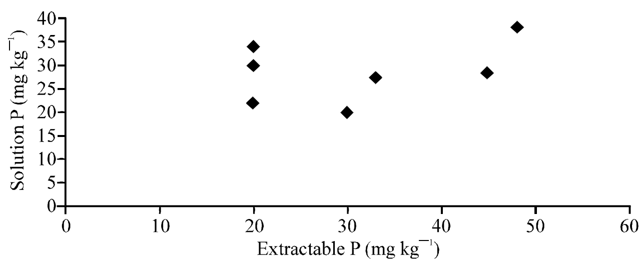

Fig. 14: Relationship between extractable P and soil solution P at 10-25 cm for BF

The general absence of relationships among the three P forms irrespective of depth and treatment suggest that the ability of the cultivated peat soils to supply P (total P) and their P concentration in available forms (extractable P or solution P) are unrelated. The findings were consistent with that of Funakawa *et al*. (1996) who also observed that even though the concentration of P in the available forms was high, the potential to supply P was not necessarily high in uncultivated peat soils. Therefore, the practical implication is that once the P in the soil solution is depleted (e.g., plant uptake, leaching etc.) there is no guarantee that a simultaneous replenishment of P will take place if no external

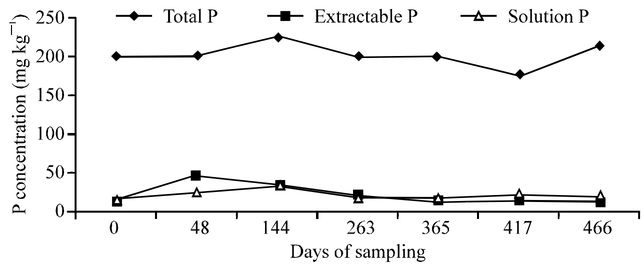

Fig. 15: Concentrations of total extractable and solution P at different periods of sampling (10-25 cm depth) for BWF

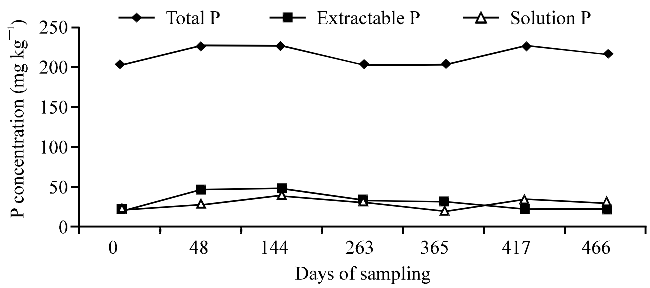

Fig. 16: Concentrations of total, extractable and solution P at different periods of sampling (10-25 cm depth) for BF

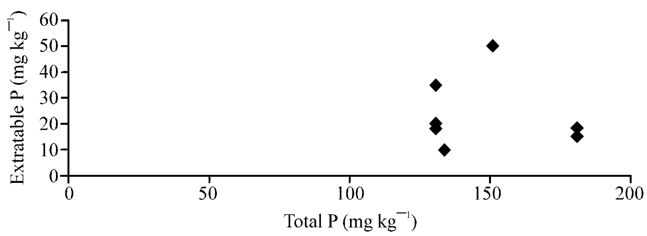

Fig. 17: Relationship between total P and extractable P at 25-45 cm for BWF

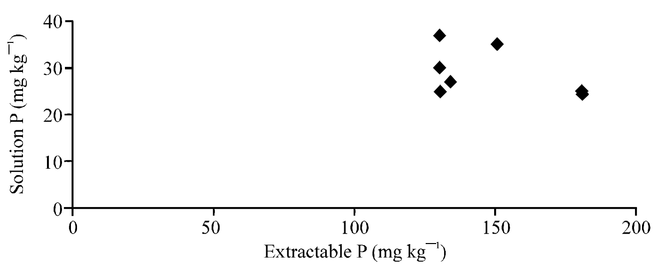

Fig. 18: Relationship between total P and soil solution P at 25-45 cm for BWF

input such as P fertilizer is timely added to the P pool of the soil. This is possible because P retention or adsorption unlike in mineral soils is weak in peat soils as a result of low bulk density (due to almost absence of clay content in peat soils) (Funakawa *et al*., 1996; Stevenson, 1994; Andriesse, 1988). Probably the low the bulk densities at the depths of 0-10, 10-25 and 25-45 cm found in this study to be 0.25, 0.16 and 0.14 g cm^{-3} might have also contributed to the poor relationship among the three

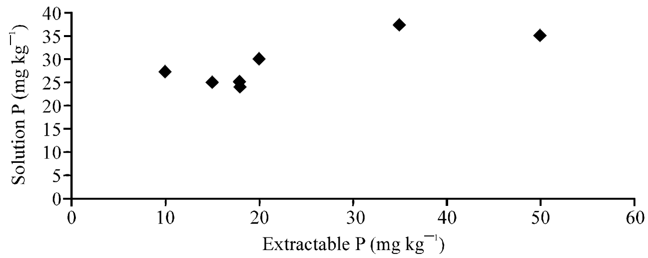

Fig. 19: Relationship between extractable P and soil solution P at 25-45 cm for BWF

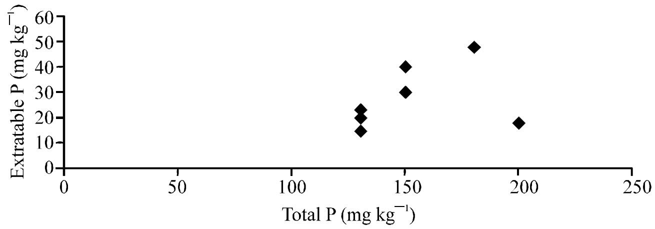

Fig. 20: Relationship between total P and extractable P at 25-45 cm for BF

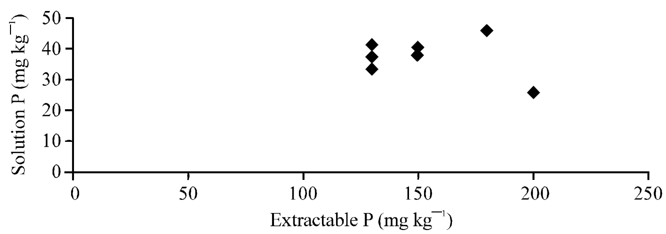

Fig. 21: Relationship between total P and soil solution P at 25-45 cm for BF

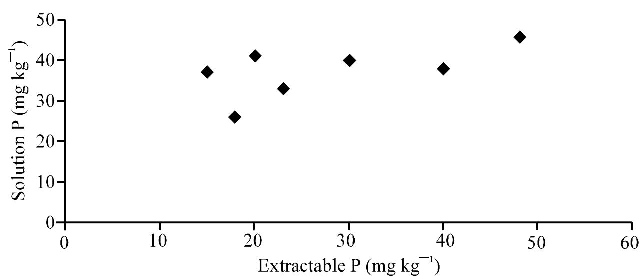

Fig. 22: Relationship between extractable P and soil solution P at 25-45 cm for BF

forms of P. It must be mentioned that the bulk densities of this study were typical of Umbro Saprists peat soil (Andriesse, 1988).

Another reason that could explain the absence of significant relationships among the three forms of P (particularly for BF) is high P leaching in organic soils because organic soils have high organic colloids and as result they generally have low capacities to adsorb P. Because their adsorbed P is normally very soluble (Fox and Kamprath, 1972), the P easily gets leached (Funakawa *et al*., 1996). As presented in Table 1, build up of total P and extractable P for BF at 0-10 cm occurred at 365 and

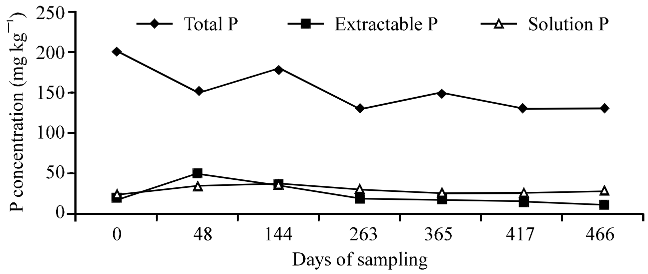

Fig. 23: Concentration of total, extractable and solution P at different periods of sampling (25-45 cm depth) for BWF

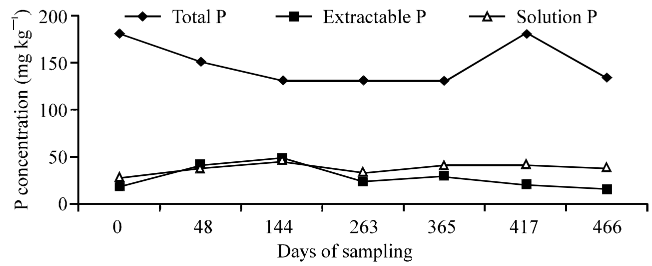

Fig. 24: Concentration of total, extractable and solution P at different periods of sampling (25-45 cm depth) for BF

Table 1: Concentrations of three different forms of soil P at different stages of sampling for 0-10 cm depth

	Sampling stage						
	0*	48	144	263	365	417	466
total P (mg kg^{-1})							
BWF	500[a]	600[a]	500[a]	433[a]	575[a]	550[a]	533[a]
BF	550[a]	700[a]	600[a]	500[a]	3900[b]	1925[b]	850[b]
Extractable P (mg kg^{-1})							
BWF	33[a]	150[a]	48[a]	40[a]	33[a]	28[a]	25[a]
BF	40[a]	200[a]	83[a]	2500[b]	550[b]	207[b]	235[b]
Solution P (mg kg^{-1})							
BWF	33[a]	48[a]	29[a]	18[a]	18[a]	23[a]	20[a]
BF	41[a]	43[a]	46[a]	89[b]	68[b]	76[b]	45[a]

* Before planting, Note: Similar alphabet within columns indicates no significant difference between means using paired t-test at $p = 0.05$

Table 2: Concentrations of three different forms of soil P at different stages of sampling for 10-25 cm depth

	Sampling stage						
	0*	48	144	263	365	417	466
total P (mg kg^{-1})							
BWF	200	200	225	200	200	175	212
BF	200	225	225	200	200	225	213
Extractable P (mg kg^{-1})							
BWF	18	45	35	20	13	13	13
BF	20	45	48	33	30	20	20
Solution P (mg kg^{-1})							
BWF	21	25	33	18	18	21	20
BF	22	28	38	27	20	34	30

* Before planting, Note: No significant difference between means within columns using paired t-test at $p = 0.05$

Table 3: Concentrations of three different forms of soil P at different stages of sampling for 25-45 cm depth

	Sampling stage						
	0*	48	144	263	365	417	466
total P (mg kg^{-1})							
BWF	200	150	180	130	150	130	130
BF	180	150	130	130	130	180	133
Extractable P (mg kg^{-1})							
BWF	18	50	35	20	18	15	10
BF	18	40	48	23	30	20	15
Solution P (mg kg^{-1})							
BWF	24	35	37	30	25	25	27
BF	26	38	46	33	40	41	37

* Before planting, Note: No significant difference between means within columns using paired t-test at p = 0.05

263 days after planting respectively. Thereafter, there was a sharp decrease of each of them till the end of the study (Table 1). There was however no significant accumulation of solution P throughout the study for both BWF and BF 0-10 cm depth (Table 1). There was however no evidence of significant accumulation of these P forms at 10-25 cm depth (Table 2) and 25-45 cm depth (Table 3). The fact the P concentrations throughout the study period were generally lower or equal to their initial status in the soil indicates P loss. This loss has been attributed to the weakness of adsorption in organic soils that renders inorganic P quite mobile with respect to leaching than in mineral soils. Besides the fact that soils with organic colloids generally have low capacities to adsorb P, adsorbed P is normally very soluble (Fox and Kamprath, 1972).

Conclusions

Irrespective of depth, there was no significant relationship among total P, extractable P and solution P in cultivated (unfertilized and fertilized conditions with burning pineapple residues in pineapple cultivation) tropical peat soils. Low bulk density and leaching seem to be the cause of the absence of a relationship.

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