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Transformations and Distributions of the Applied and Native Phosphorus into Different Phosphorus Pools in Incubated Rustenburg and Loskop soils

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***Abstract* – A study was carried out on the transformations and distributions of applied and native soil phosphorus (P) into different pools in the two soils, a Ferric Luvisol from Rustenburg which is a high P fixing and a Ferric Acrisol from Loskop a low P fixing. They were examined after treatments with different P rates (0, 25, 50, 100, 150, and 200 mg kg^{-1}), and incubation periods (1, 60, 120, 180, and 240 days) under laboratory conditions, at ARC – IIC in Rustenburg, South Africa. A sequential P extraction procedure was carried out on each treatment combination to determine the changes in (a) soluble and labile, (b) adsorbed, and (c) occluded and residual P pools in each soil. The results showed that while solution and labile P decreased with time of incubation, there were corresponding increases in adsorbed, occluded and residual P. Loskop soil had more marked increases in solution and labile P than the Rustenburg soil, which showed higher values for the adsorbed, occluded and residual P forms. Approximately 30 to 60 % of the added P was transformed into less labile P pools in one day and 80-90 % of the added P after 60 days of incubation. This transformation was very well marked in the higher (Rustenburg) than in the lower (Loskop) P fixing soil. A major proportion of the P transformation was to the NaOH extractable inorganic P (P$_i$) pool (adsorbed P pool). The added P desorbed from this pool was fairly constant (about 30 %) for the different incubation periods.**

***Keywords* – P Adsorption, P Desorption, P Distribution, P Fractionation, Sequential Extraction, P Transformation.**

I. INTRODUCTION

Phosphorus deficiencies in plants constitutes the second most important soil fertility problems throughout the world [1]. [2] have also indicated that P is the second most limiting element in the Alfisols, Oxisols, and Ultisols of tropical and sub-tropical Africa, Asia, and South America. Phosphorus deficiencies in such soils are often exacerbated by their high capacities to fix P in different forms making it less available to crops. As phosphate fertilizer is one of the most expensive inputs for the production of crops, it is essential not only to know the most cost effective P application rates and methods but also the long-term effects of the added P in the soil. An attempt to quantify P-fixation, including P fractionation procedures to characterize different inorganic P pools has been made [3], [4] proposed a procedure that allowed for a more complete characterization of soil P and reported that the sequential fractionation procedure they proposed could be used to record changes in soil P that occur during short-term incubation experiments. This procedure has since been used in different soils worldwide to study the transformations and distribution of inorganic and organic P forms in soils [5]. [6] re-grouped the P fractions based on the rates of their transformations into different P pools. This allowed for the development of a more dynamic picture of P transformations in soils. A method for the assessment of long-term P desorption studies of soils using hydrous ferric oxide in dialysis membrane tubes (DMT-HFO) as a P sink, was also proposed by [7].

Phosphorus deficiencies due to P sorption (fixation) in South Africa are widespread especially in the highly weathered soils in the high rainfall areas. [8] determined the P-sorption isotherms of 50 soils from a number of localities in the Kwazulu-Natal Province and found amounts of P sorbed ranged from 5 to 1174 mg kg^{-1}. In a long-term field experiment (over 15 years) on a yellow brown sandy clay loam and a red sandy clay soil in the highveld of the Mpumalanga Province [9], found that the NaOH-extracted inorganic P (P$_i$) (moderately adsorbed P) showed the largest decrease of inorganic P and was deduced to be mainly responsible for the replenishment of the labile P pool over time [10] and [11].

II. MATERIALS AND METHODS

2.1 Study site

The two soils were sampled from Agricultural Research Council – Institute for Industrial Crops, Rustenburg situated at 25.7 ^{0}S / 27.3 ^{0}E in the North West Province, and the affiliated Loskop Experimental Farm (25.2 ^{0}S / 29.4 ^{0}E) near Groblersdal in Mpumalanga Province in South Africa. The Rustenburg soil is a high P fixing (red-sandy clay soil) Ferric Luvisol [11] and the Loskop soil is a low P fixing (red sandy loamy soil) Ferric Acrisol (FAO, 2006). Composite soil samples of 200 kg (0-30 cm) each from the respective sites were air dried and ground to pass a 2 mm sieve. Each soil sample was analysed for pH, total N, organic carbon, P (Bray 1, 2, and total P), exchangeable K, Ca, Mg, texture and clay mineralogy according [12] and modified by [13].

To 500 gm soil samples, the equivalent of 0, 25, 50, 100, 150, and 200 mg P kg^{-1} were added as KH_2PO_4, mixed thoroughly with the soil and watered to field capacity. The treated soils were incubated for 1, 60, 120, 180, and 240 days in a room at 20 ^{0}C (+ or – 2 ^{0}C). Each treatment combination was replicated three times using completely randomised design (CRD) arrangement of treatments. At the end of each incubation period, the replicated samples of each P treatment were sampled, air-dried, ground in preparation for the sequential P-extractions.

2.2 Soil analytical procedures

A sequential P-extraction procedure was carried out on the dried (2 mm) soil samples as described by [13] with a slight modification, where the resin strips were replaced by dialysis membrane tubes (DMT) filled with hydrous ferric oxide (HFO), as outlined by[7]. The P fractionation procedure used consisted of the following steps: 1.0 g soil sample in deionized water was extracted for soluble-P with a dialysis membrane tube filled with (DMT-HFO) followed by extraction with 0.5M $NaHCO_3$ (labile – P_i and P_o), 0.1M NaOH (Al-, Fe-oxihydroxide bound P i.e. slow-labile - P_i and P_o), 1.0M HCl (Ca - bound P i.e. slow-labile - P_i), concentrated HCl (occluded/recalcitrant fixed P_i and P_o), and concentrated H_2SO_4 + H_2O_2 (residual/recalcitrant/lattice fixed P_i). In each extraction procedure the soil suspension was horizontally gently shaken for 16 hours. The extracted P was determined in solution according to the colorimetric method described by Murphy-Riley (1962) modified by [13].

The data from the experiments were analysed statistically using a "GenStat" version 13 package computer programme. The Analysis of Variance (ANOVA) was done to determine whether F values were statistically different. The Least Significant Differences (LSD Fisher's test at 5% confidence level) were applied to separate treatment means. The regression equations and correlation coefficients were determined with the exponential fits of the graphs. The percent P recovered was calculated using the formula: % P = (P*x*–P*o*)/P1*100; where P*x* was P in the *x*th fraction of the P treatment (i.e. 25, 50, 100, 200), and P*o* was P in the *o*th fraction of the initial no P (P0) treatment (i.e. where no P was added), while P1 was the applied P level.

III. RESULTS AND DISCUSSION

According to some selected properties of the two soils given in Table 1, the Rustenburg soil is a sandy-clay (51 % clay) while the Loskop soil is a sandy-loam (19 % clay). Kaolinite is the dominant clay mineral in both soils (Rustenburg 52%; Loskop 37%). The pH (H_2O: 1:2.5 suspension) of the soils were near neutral. The organic carbon content was low for both soils although it is a little bit higher in the Rustenburg soil. Native P contents (Bray 1) were generally low for both soils. According to [14], Bray 1 gives the best indications of labile P in the slightly to highly weathered soils. However, the Total P was far higher for the Rustenburg soil than the Loskop soil. The rest of the differences in the physical and chemical properties could be mainly due to the differences in clay and sand contents.

Table 1: Chemical, physical, and mineralogical, characteristics of Rustenburg and Loskop soils

Parameter/ Attribute	Rustenburg		Loskop		Parameter/ Attribute	Rustenburg		Loskop	
Depths (cm)	30	60	30	60	Depths (cm)	30	60	30	60
pH (H_2O)	5.87	6.82	6.84	6.47	Textural Class	Sandy-clay	Clay	Sandy-loam	Sandy-clay loam
Organic C (mg kg^{-1})	6700	5800	4100	3900					
Total N ,,	486	419	206	163					
Bray 1 P ,,	5.0	3.0	12.5	1.0	Sand (%)	42	38	81	72
Bray 2 P ,,	8.0	4.5	16.5	1.0	Silt ,,	7	7	0	1
Total P ,,	265	202	153	97.5	Clay ,,	51	55	19	27
Exchangeable					Kaolinite ,,	52	54	37	26
cations (cmol kg^{-1}):					Quartz ,,	29	35	52	74
K ,,	0.64	0.46	0.51	0.25					
Ca ,,	2.28	2.13	1.60	1.80					
Mg ,,	2.85	3.00	0.83	1.00					

(1) The impacts of the added P on the DMT-HFO and 0.5M NaHCO3 extractable P pools (soluble and labile P pools) after different incubation periods

(a) The DMT-HFO extractable P

The results presented in Fig. 1a and b, show that, the extracted DMT-HFO-P_i fraction increased significantly with increasing P application rates in the two soils but decreased significantly with increasing incubation periods. This agrees with [15] and [16] who reported that a fair amount of soluble P added to a soil is usually adsorbed and precipitated rapidly and that the concentrations in solution continue to decline slowly over a period of time. The decrease in extractable P in the Rustenburg soil was more pronounced during the first 60 days while this change took place in 120 days in the coarser Loskop soil. This difference was possibly due to the P fixation abilities of the two soils. These P fixation abilities are related to soil texture. The increased P sorption occurs in clayey soils with large surface areas, high organic carbon contents, and predominantly 1:1 type clay materials (i.e. highly weathered red and yellow-brown clay soils) [10] and [11].

The DMT-HFO-P_i extracts in the Rustenburg soil (Fig. 1a) ranged from 2.50 and 40.10 mg kg^{-1} after one day to 2.80 and 12.60 mg kg^{-1} after 240 days of incubation in the 0 and 200 mg P kg^{-1} treatments, respectively. This represented percentage P recovery of 28.90 and 18.80% for the 25 and 200 mg P kg^{-1} treatments after 1 day and only 7.35 and

4.90% after 240 days of incubation. This also shows that the DMT-HFO-P_i extracted only a small fraction of the total soil P pool varying from 1.35% with no P added to 10.75% with 200 mg kg^{-1} added P after one day to only 1.30-3.00% for the 0 and 200 mg P kg^{-1} treatments respectively, after 240 days of incubation.

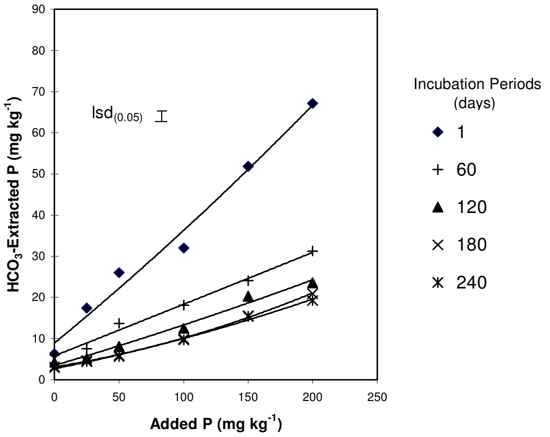

FIG. 2a: The effects of the added P and incubation time on the bicarbonate (HCO_3) extracted inorganic P (P_i) of Rustenburg soil.

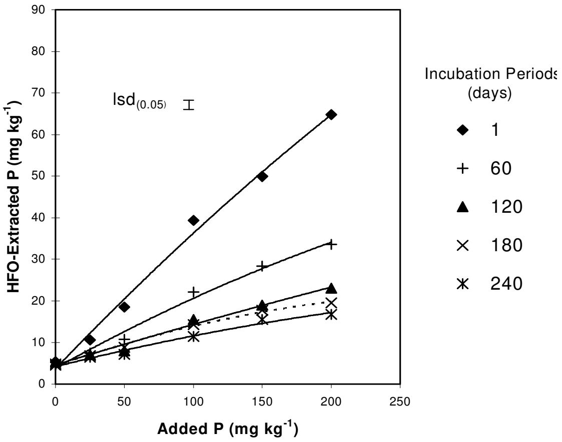

FIG. 1b: The effects of the added P and incubation time on the DMT-HFO extracted inorganic P (P_i) of Loskop soil.

The corresponding values for the Loskop soil (Fig. 1b) showed the same trend but differed in that more P was extracted than from the Rustenburg soil. The values varied from 5.40–64.80 mg kg^{-1} after 1 day to 4.55-16.75 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments, respectively. These represent P recoveries of 21.10-29.70% (1 day) to 7.70-6.10 % (240 days) for 25 and 200 mg kg^{-1} added P respectively. The proportion of the DMT-HFO extracted P_i also constituted only a small fraction of the total soil P, ranging from 3.85-19.50 % after 1 day to 2.85-4.65 % after 240 days for the 0-200 mg P kg^{-1} treatments that was relatively higher than for the Rustenburg soil. The fact that more DMT-HFO-P_i was extracted from the Loskop than from the Rustenburg soil indicates that the Rustenburg soil had a higher P fixation capacity. The differences between the soils may have been due to differences in clay and organic matter contents and the clay type [17], 2015).

(b) The bicarbonate extractable Pi

The extracted HCO_3-P_i fraction increased significantly ($P = 0.01$) with increasing levels of added P for both soils. However, the amounts extracted for each level of added P decreased significantly with increasing time of incubation, similar to the DMT-HFO-P_i extracts for both soils (Figs. 2a and 2b).

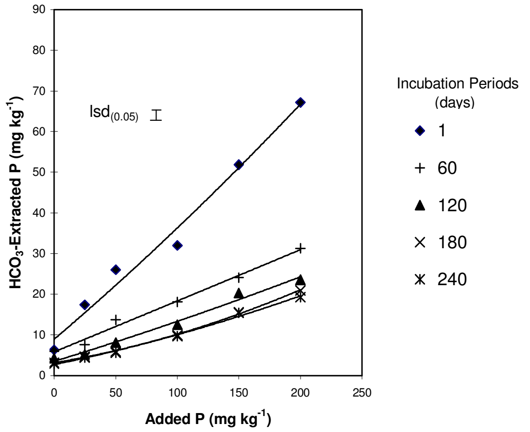

FIG. 2a: The effects of the added P and incubation time on the bicarbonate (HCO_3) extracted inorganic P (P_i) of Rustenburg soil.

In the Rustenburg soil the amounts of HCO_3-P_i extracts varied from 6.30 and 67.15 mg kg^{-1} after 1 day between the lowest and highest rates of applied P to 2.90 and 19.25 mg kg^{-1} after 240 days, respectively (Fig. 2a). This represented a percent P recovery of approximately 30% after one day, but the recovery was reduced to approximately 10% after 60 days and even lower for longer incubation periods.

In the Loskop soil (Fig. 2b) the changes in percent P recovered were more gradual up to 180 days of incubation. This again clearly shows the differences between the two soils. Whereas in the Rustenburg soil the added P was transformed within the first day and 60 days of incubation, after which only small amounts of HCO_3-P_i could be extracted. For the Loskop soil, the transformation was slower, and fairly a large percentage of the applied P was extractable up to 180 days of incubation (Fig. 2b). The contributions of HCO_3-P_i to the total soil P pool were initially relatively low for the Rustenburg compared to the Loskop soil. The contributions increased with P rates but were markedly reduced with increasing incubation periods. This indicates that both soils lost large proportions of HCO_3-P_i to other P pools during the incubation periods.

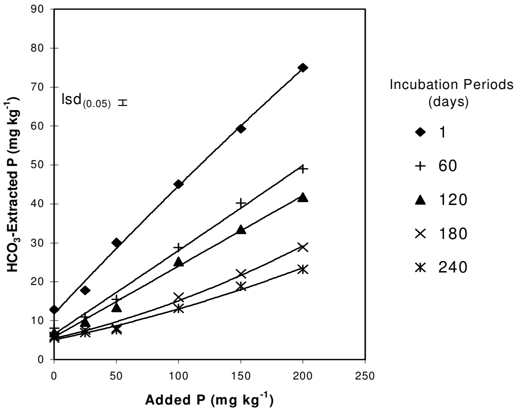

FIG. 2b: The effects of the added P and incubation time on the bicarbonate (HCO_3) extracted inorganic P (P_i) of Loskop soil.

(c) The bicarbonate extractable Po

The amount of bicarbonate P_o (HCO_3-P_o) extracted at all rates of added P were slightly higher for the Rustenburg than for the Loskop soil during the 120 days of incubation. For longer incubation periods extractable P_o became very low indicating that most of the organic P was mineralized within 120 days, thereafter it became more or less depleted (Fig. 3a, b).

The contributions of HCO_3-P_o as fractions of the total extracted soil P were generally low for both soils. For example, the Rustenburg soil values ranged from 4.16-2.19% between 1 and 240 days of incubation. While for the Loskop soil the values fell between 4.77 and 2.48% during the same period. In a related long-term field trials [9] found similar values with Avalon and Clovelly soils in Mpumalanga Province in South Africa. Although [18] reported that resin P (which could be roughly equated to HFO-P_i) was largely controlled by the mineralization of P_o, and that 80% of the availability in resin P was accounted for by variations in bicarbonate P_o. Data from the Rustenburg and Loskop soils show that in general the contributions of the bicarbonate P_o were marginal (Figs 3a, b).

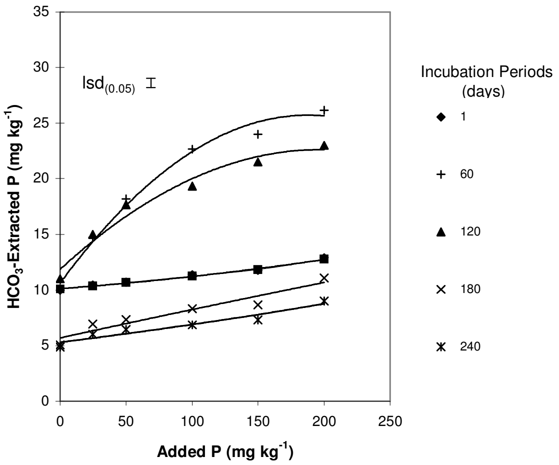

FIG. 3a: The effects of the added P and incubation times on the bicarbonate (HCO_3) extracted organic (P_o) of Rustenburg soil.

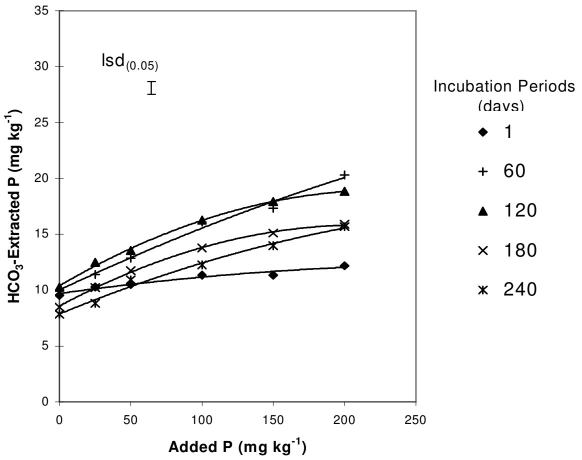

FIG. 3b: The effects of the added P and incubation times on the bicarbonate (HCO_3) extracted organic (P_o) of Loskop soil.

(2) The influence of the added P on the 0.1M NaOH and 1.0M HCl extractable P pools (adsorbed P pools) after different incubation periods

(a) The hydroxide extractable Pi

Data presented in Fig. 4a and b show that the 0.1M NaOH-extracted P_i increased significantly ($P = 0.01$) with P rates and increasing incubation periods. For the Rustenburg soil (Fig. 4a) increases were from 30.00 and 82.55 mg kg^{-1} after 1 day to 34.35 and 94.40 mg kg^{-1} after 60 days and to 46.70 and 104.00 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments, respectively. This represents a P recovery of 23.20-26.30 % after one day, 30.70-30.00 % after 60 days and 27.90-28.65 % after 240 days of incubation for the 0 and 200 mg P kg^{-1} treatments, respectively (Fig. 4a). This showed that a significant proportion of the applied P was transformed into this fraction and that the proportion in this pool increased with time.

The values for the Loskop soil varied from 21.45 and 62.25 mg kg^{-1} after 1 day to 26.40 and 73.25 mg kg^{-1} after 60 days and to 37.85 and 96.10 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments, respectively. However, the changes in the extractable P were more gradual up to 240 days of incubation (Figs. 4b). The fact that the percent P recovered between the two soils were relatively close

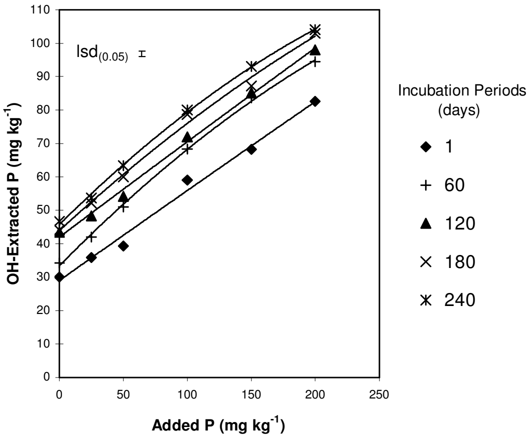

FIG. 4a: The effects of the added P and incubation time on the hydroxide (OH) extracted inorganic P (P_i) of Rustenburg soil.

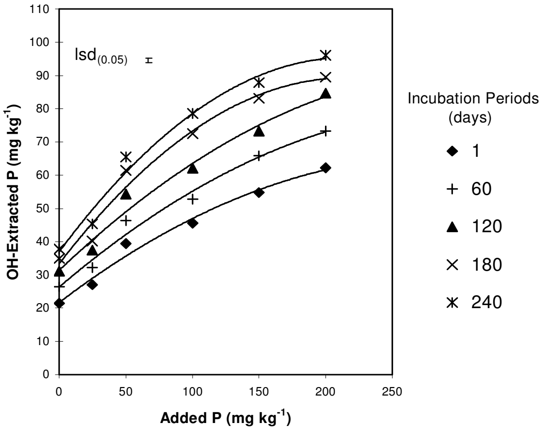

FIG. 4b: The effects of the added P and incubation time on the hydroxide (OH) extracted inorganic P (P_i) of Loskop soil.

indicates that the transformation reactions or patterns for the added P were similar but only the amounts varied. The results showed that this pool contributed approximately 25% of the total extracted soil P, thus the highest contribution to the total soil P_i pool in the two soils.

(b) The hydroxide extractable Po

The actual contributions of this P fraction to the total soil P pool were relatively small (Rustenburg, 5-7% and Loskop, 4-6%). The percentage contributions increased with the rates of added P but generally decreased with the increasing incubation periods after climaxing at 60 days. Both soils gained more or less (slightly higher for Rustenburg) equal shares of OH-P_o in relation to other P fractions with the increasing P rate during the incubation period (Fig. 5a, b). Thus, the extracted OH-P_o fraction in the Rustenburg soil accounted for (lowest and highest average values) 5.53% and 7.09% of the total soil P after 1 and 60 days of incubation, respectively. While for the Loskop soil, OH-P_o accounted for 4.25% and 6.54% of the total soil P after 1 and 240 days of incubation, respectively. These values are again comparable to [9] findings from the Avalon and Clovelly soils. However, the values were lower than those of [3] who reported that OH-P_o was an average of 15% of the total soil P from long-term wheat rotation experiment dating from 1911 to 1982.

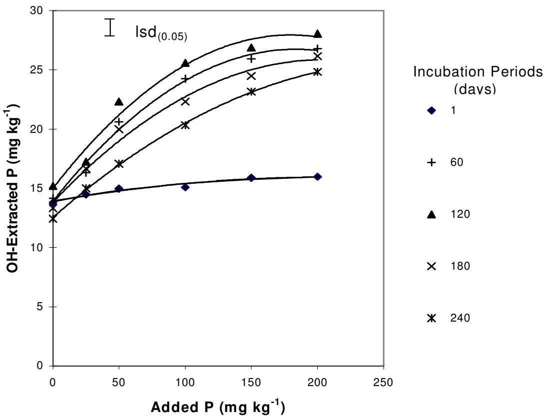

FIG. 5a: The effects of the added P and incubation times on the hydroxide (OH) extracted organic P (P_o) of Rustenburg soil.

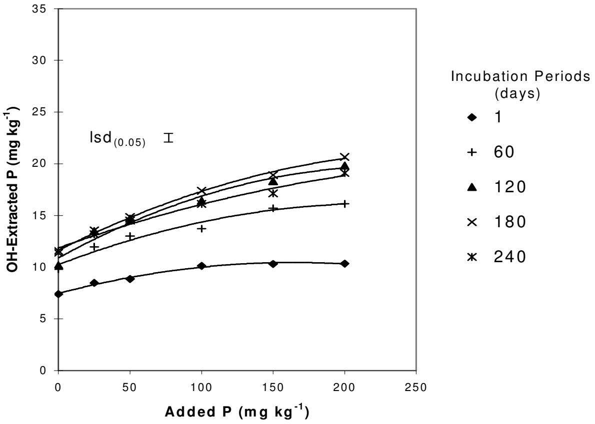

FIG. 5b: The effects of the added P and incubation times on the hydroxide (OH) extracted organic P (P_o) of Loskop soil.

(c) The dilute hydrochloric acid extractable Pi

The 1.0M HCl-extracted P from the Rustenburg soil increased from 6.75 and 15.10 mg kg^{-1} after 1 day to 8.85 and 27.20 mg kg^{-1} after 240 days of the 0 and 200 mg P kg^{-1} treatments, respectively (Fig. 6a). The percent P recovered however decreased with increasing P rate indicating that the transformation of added P to Ca-bound-P_i was slower than to –OH-P_i which took place fairly rapidly. The Loskop soil showed similar trends except that the recovery was lower than for the Rustenburg soil (Fig. 6b). In both soils the extracts accounted for a small percentage of the total soil P pool. [9] reported that this fraction contributed less than 1% of the total soil P pool in a sandy loam soil.

However, the high Ca and Mg in the Rustenburg soil could have resulted in a higher degree of precipitation of the applied P as Ca-P and possibly also as Mg-P, both being less available than Al-P or Fe-P. This in part may also explain why the P applied in the Rustenburg soil remains relatively more unavailable to crop plants than in the Loskop soils [19]; [15]; [20].

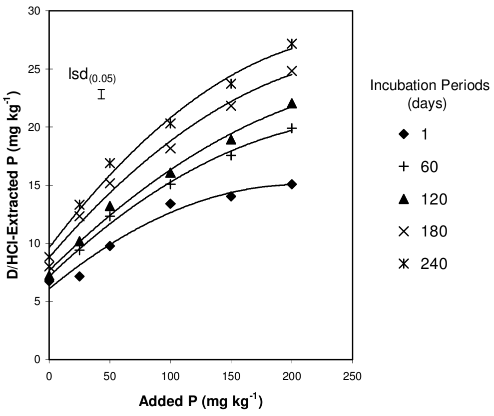

FIG. 6a: The effects of the added P and incubation times on the dilute hydrochloric acid (HCl) extracted inorganic P (P_i) of Rustenburg soil.

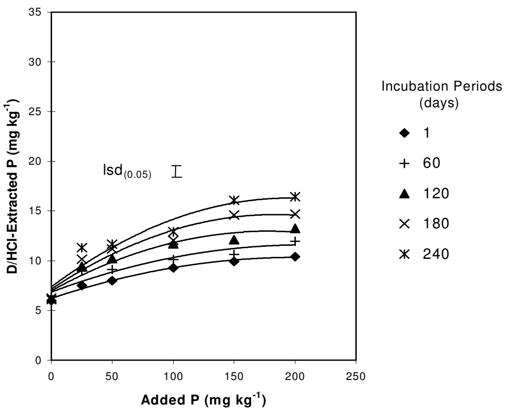

FIG. 6b: The effects of the added P and incubation times on the dilute hydrochloric acid (HCl) extracted inorganic P (P_i) of Loskop soil

(3) The impact of the added P on the concentrated HCl and concentrated H_2SO_4 + H_2O_2 extractable P pools (insoluble and residual P pools) after different incubation periods

(a) The concentrated hydrochloric acid extractable Pi

Data presented in Fig. 7a and b show that the concentrated HCl extracts from the Rustenburg soil were relatively higher ranging (for the lowest and highest rates of P applied) from 50.95 and 63.75 mg kg^{-1} after 1 day to 59.60 and 100.55 mg kg^{-1} after 240 days of incubation. This represented a P recovery of 2.70-6.40% after 1 day and 20.10-20.50% after 240 days of incubation between rates of 25 and 200 mg kg^{-1} added P, respectively. This fraction contributed on average more than 20% of the total extractable soil P pool. Corresponding values for the Loskop soil were lower ranging from 29.35 and 39.90 mg kg^{-1} after 1 day to 34.85 and 71.10 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments and P recoveries of 11.75-5.30 after 1 day and 18.35-18.15% after 240 days of incubation for the 25 and 200 mg kg^{-1} treatments, representing between 15 and 20% of the total soil P pool. The fact that the regression models (Figs. 7a and b) were straight lines indicated that no equilibrium was attained and that the transformation of the added P to this pool would require longer incubation times.

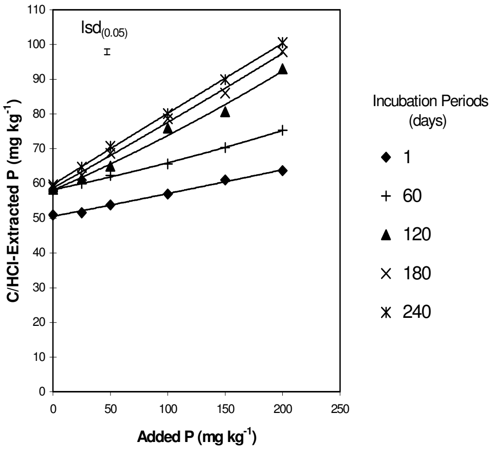

FIG. 7a: The effects of the added P and incubation times on the concentrated hydrochloric acid (HCl) extracted inorganic P (P_i) of Rustenburg soil.

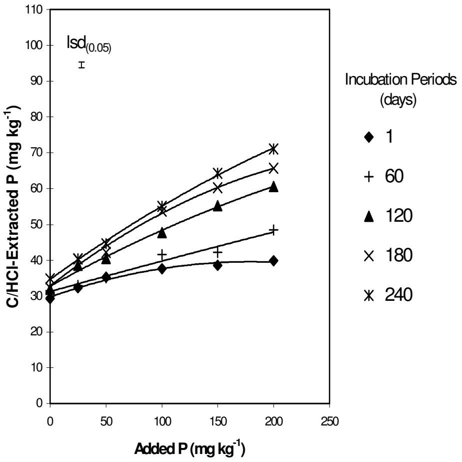

FIG. 7b: The effects of the added P and incubation times on the concentrated hydrochloric acid (HCl) extracted inorganic P (P_i) of Loskop soil.

(b) The concentrated hydrochloric acid extractable Po

This fraction also contributed just a small part of the total soil P pool. The P recovery rates for the Rustenburg soil were relatively low averaging 1.87% on day one to 6.01% after 240 days of incubation. While the percentage contributions to the total extracted P pool were limited and varied from 4.17% to 6.23% between 1 and 240 days of incubation.

The Loskop soil had average P recovery rates of 1.27% on the first day and 7.77% after 240 days of incubation. The percentage contributions to the total extracted P pool varied from 4.52% to 6.59% during the incubation time. Thus, the contributions of the concentrated HCl-P_o extracts to the total extracted P were noticeably low and did not vary much for both soils and were comparable to the HCO_3-P_o and OH-P_o. In their work, Hedley et al. (1982) and [9] also reported very low values for concentrated HCl-P_o extracts.

Thus, while bicarbonate-P_o and hydroxyl-P_o decreased during 240 day incubation in both soils, the concentrated HCl-P_o generally remained stable with only marginal increments over the incubation period. As it has been indicated earlier, it is assumed that P_o extracted by the -HCO_3 is labile, -OH - P_o is from adsorbed forms, while the concentrated HCl-P_o is occluded or residual in nature. It has been suggested that the majority of P_o forms in 0.5M $NaHCO_3$ and 0.1M NaOH fractions are of smaller molecular weights of < 30,000 (i.e. readily to moderately decomposable) while the occluded or residual P_o (conc. HCl-P_o extracts) are compounds of larger molecular weights that correspond to the humic acid and humic fractions, which are stable, and not readily subject to losses with time [21], [22]. Therefore the noted increases in extractable P_o with increasing incubation periods for all the three fractions (HCO_3-P_o, OH-P_o and conc. HCl-P_o) could indicate that some of the added P_i was included with the P_o fractions. This may have been an inherent experimental error in the differentiation of P_i and P_o. [23].

(c) The concentrated sulphuric acid extractable P

The concentrated H_2SO_4–P extracts were very similar to those of the concentrated HCl-P_i (Figs. 8a and b). The extracts for the Rustenburg soil were very high varying from 55.30 and 61.70 mg kg^{-1} after 1 day to 61.85 and 99.20 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments, respectively. This represented recoveries of 3.60-3.20% after one day and 15.35-18.70% after 240 days of incubation for the 0 and 200 mg P kg^{-1} treatments. This fraction represents approximately 20-25% of the total soil P pool. Corresponding values for the Loskop soil were lower ranging from 39.85 and 45.70 after 1 day to 42.60 and 79.80 mg kg^{-1} after 240 days for the 0 and 200 mg P kg^{-1} treatments (Fig. 8b). The recoveries were very low initially at only 0.70-2.90% after 1 day but increased to 6.70-18.60% after 240 days of incubation for the 0 and 200 mg P kg^{-1} treatments. This fraction also represents approximately 20% of the total extracted soil P pool. These findings were comparable to those of [24] and [9].

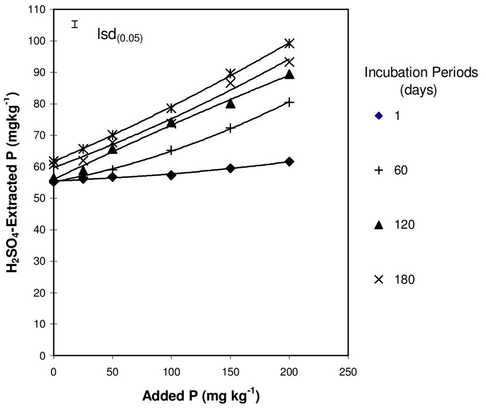

FIG. 8a: The effects of the added P and incubation times on the concentrated sulphuric acid (H_2SO_4) extracted residual P (P_i) of Rustenburg soil.

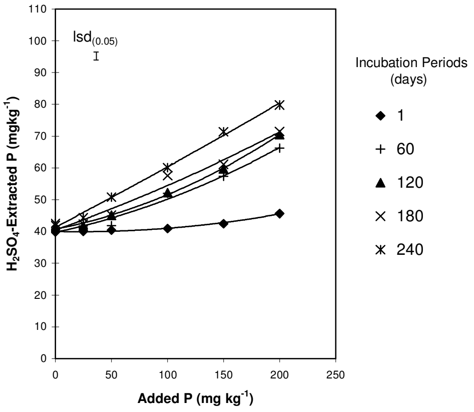

FIG. 8b: The effects of the added P and incubation times on the concentrated sulphuric acid (H_2SO_4) extracted residual P (P_i) of Loskop soil.

(4) The effectiveness and limitations of the methodologies used

In our experiments the resin strips technique in the [6] method was replaced by a desorption technique developed by [7] that is based upon the use of hydrous ferric oxide (HFO) as a sink for P. Instead of being impregnated in filter paper, the HFO is present inside dialysis membrane tubing (DMT). The membrane seemed to have provided an excellent means to separate the soil suspension from the P sink. No HFO passed through the membrane and the sink was easily separated from the soil suspension with virtually no loss of soil materials after desorption. As such, this technique showed important advantages over the previous resin methods.

As a whole the sequential P extraction procedures proved very effective. The amounts extracted varied from 96-107% and 95-104% of the expected total P from Loskop and Rusteburg soils respectively. However, there were some inherent sources of error in the determination of P_o. This is because the P_o was determined by the difference between P_t and P_i in each extract [6]. The P_i was determined in the supernatant after precipitation of organic matter with acid, and any P_i that precipitated along with the organic matter could have caused some errors in the calculations of the P_o (P_t-P_i). It has so far not been possible to quantify the P_o overestimation [6].

The overestimations could have resulted in the relatively higher levels of P_o extracted from both soils. But, this fractionation procedure is reported to be currently the only one that can be used with moderate successes for the evaluation of soil P_o. According to [6] the original fractionation of [3] left between 20 and 60% of the P in the soil un-extracted. This residue often contained significant amounts of P_o that sometimes participated in relatively short-term transformations.

IV. CONCLUSION

The sequential P extractions identified the P quantities transformed and distributed to different pools and how much of the added P could be desorbed or recovered from each pool after different incubation periods. In general, the sequential P extractions were very effective in that the total recovery of the added P was close to 100%. The results showed that approximately 30 to 60% of the added P was transformed into less labile P pools within one day and 80-90% after 60 days. This transformation was more marked in the Rustenburg (with higher P fixation capacity) than the Loskop soil (with lower fixation capacity). A major part of the P transformation was to the OH-P_i (adsorbed P). The recovery from this pool was fairly constant (approximately 30%) for the different incubation periods. Thus, while solution and labile P decreased with time of incubation, there were corresponding increases in adsorbed, occluded and residual P. Loskop soil had more marked increases in solution and labile P than the Rustenburg soil, while the Rustenburg soil showed higher values for the adsorbed, occluded and residual P forms. The noted differences could explain the reportedly higher levels of P fixation (adsorption and/or precipitation) by the Rustenburg than by the Loskop soil.

Therefore, in order to maximize fertilizer P efficiency especially in high P fixing soils like the Rustenburg soil, band placement at planting time should be recommended, as the findings show that after 1 day of incubation 60% of the added P was transformed into less labile P. When band placed the soil in the vicinity of the band will be saturated with P and some P will remain in more labile form and thus available for a longer period of time. The use of plants with well-developed root systems could also be recommended to ensure that the roots explore the soil volumes more effectively and thus reach the added fertilizer and native P transformed into more stable (immobile) P pools.

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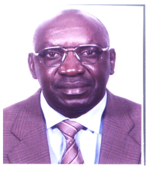

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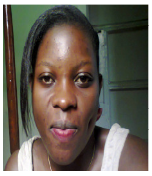

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