CHAPTER 3

A STUDY OF THE EFFECTS OF DIFFERENT P APPLICATION RATES AND INCUBATION PERIODS ON P DESORPTION RATES AND CHANGES IN P POOLS WITH SUCCESSIVE DMT-HFO EXTRACTIONS ON A HIGH AND LOW P FIXING SOILS

INTRODUCTION

Phosphorus deficiency in moderate to highly weathered soils is often exacerbated by a high capacity to fix it in different ways making it less available to crop plants (Sanchez, 1976; Sanchez and Salinas, 1981; Pushparajah and Bachik, 1987; Doula et al., 1996). As phosphate fertilizer is an expensive input, it is essential not only to know the most cost effective phosphate application rate but also to make maximum use of the natural and applied P in the soil that may have accumulated due to previous over application of P fertilizer. There could therefore be a significant residual effect due to the possible desorption of phosphate from the different soil P pools and when this benefit is ignored it could lead to unnecessarily high P applications (Quang et al., 1996).

Although P deficiency is very common in countries with limited access to fertilizers, it is particularly acute in soils in the humid tropics and subtropics because these soils are often rich in metal oxihydroxides that form strong bonds with phosphate anions. Other soil characteristics such as pH, clay and organic matter content, exchangeable cations, ionic strength, redox potential, and temperature may also influence P sorption (Quang et al., 1996). It is important therefore to collect data on how P react in different soils to improve fertilizer practices. Because of the implications of fertilizer efficiency on plant growth, soil P adsorption/desorption reactions are important aspects in these investigations (Sattell and Morris, 1992; Doula et al., 1996; Indiati, 1998).

Successive cropping experiments can be carried out in field or greenhouse conditions to quantify the residual plant-available P in soils. In such experiments, plants remove plant-available P until P deficiency occurs or a response to the added P is measured (Mckean and Warren, 1996; du Preez and Claassens, 1999). This approach, however, is very expensive and time consuming, and methods that approximate a biological measure can be very useful analytical tools in P fertility studies in soils (Indiati, 1998).

The conventional routine chemical extraction of soil P removes only a fraction of the so-called plant-available P from the total soil P that correlates with plant response. In addition, such extractants cannot be used to assess the potential desorption rate of P, because they disrupt the chemical structure of the soil. Some soil test methods have limited effects on the soil system, such as dialysis membrane filled with hydrous ferric oxide (DMT-HFO) (Amer et al., 1955; Dalal, 1985; Menon et al., 1990; Freese et al., 1995). Such a method extracts more of the "plant-available P" than the chemical procedures. It estimates the labile P pools and is a good indicator of the total plant available P simulating the processes involved in P uptake by plant roots in soil better. In fact, DMT-HFO serves as a sink for released P, preventing solution P built up to levels where further P release is inhibited. Successive extractions carried out by this method could constitute a convenient laboratory method to characterize the capacity of soil to supply P, and to investigate the rates of P release from the natural and fertilizer P in soils over a period of time (Indiati, 1998).

The choice of a suitable extraction method to evaluate available P must take into account the changes within the soil P pools. These include the relationships between soil P forms and the available P status, and the transformations of the soil P pools in relation to different levels of added P, time of incubation, and the soil properties (Sharma et al., 1980; Debnath and Mandal, 1982; Tekalign and Haque, 1991; Indiati et al., 1992).

Thus, a desorption technique for soil P has been proposed, in which the dialysis membrane tubes filled with hydrous ferric oxides (DMT-HFO) are used as P sinks to

continuously remove P from the soil solution in a way that simulates the mechanism of P absorption by plant roots (Freese et al., 1995). The system was reported to be mechanically stable for long reaction periods (over 500 hours). After the desired time of contact between soil suspension and P sink, the sink could easily be separated from the soil suspension with practically no loss of soil material. This technique thus had important advantages over the resin methods (Freese et al., 1995, Lookman et al., 1995).

Previous studies with the two South African soils from Rustenburg and Loskop with high and low P fixing capacities respectively

In Chapter 2, the two South African soils (Rustenburg and Loskop) were used in a study to investigate the changes and distribution in the different P pools as influenced by different levels of added P and incubation time. Since the pH in both soils ranged from medium acidity to low alkalinity, it was therefore assumed that added P could be adsorbed and/or fixed to varied degrees by Al- and Fe- oxihydroxides, soil organic matter, layer silicate clays, or precipitated as Ca and Mg phosphates.

The results of sequential P fractionations showed that in both soils solution and labile P decreased with time of incubation, while there were corresponding increases in adsorbed, occluded and residual P. In the Loskop soil the transformations and distribution of the added P to different P pools were slower than in the Rustenburg soil, which also had a higher capacity to change the added P into less labile P forms. The noted differences could explain the reportedly higher levels of P fixations (adsorptions and /or precipitations) by the Rustenburg than by the Loskop soil. Although a larger proportion of the added P was transformed into more stable (immobile) P forms, it does not mean that this non-labile P can't become available to plants over time due to P desorption processes.

Thus, having determined the extent of P fixations by the two soils, it became necessary to establish how much of this transformed or fixed P can become available to plants over time and at what rate.

MATERIALS AND METHODS

1: MATERIALS

1.1: Soils

In this experiment, the two soils from Rustenburg and Loskop previously described in Materials and Methods, Section 1 of Chapter 2 were used. The details of some selected characteristics are contained in Table 1 (Chapter 2).

1.2: Incubation materials

- 1000 cm^3 glass jars
- Cardboard boxes, - to hold 12 glass jars
- KH_2PO_4
- Climate room (20^0 C; + or – 2^0 C)

2: SOIL INCUBATION TRIALS

2.1: Soil sampling and Preparations

Soils from Rustenburg and Loskop were used in the trials. Soils sampling and preparations were described in detail in Materials and Methods, Section 2.1 (Chapter 2). The soil samples were dried in a forced air oven at 40 ^{0}C, and ground to pass a 2 mm sieve. Each bulk sample was thoroughly mixed and stored at room temperature.

2.2: P-Treatments

Soil samples were treated to different P application rates, incubated for different periods, and subjected to different DMT-HFO extraction times. Each 500 g sample of the two soils received one of the five P rates of 0, 25,

50, 100, and 200 mg kg^{-1} applied as KH_2PO_4. After thorough mixing the soils were stored in 1 000 cm^3 glass jars. The soil samples in the glass jars were then brought to field capacity before the incubation processes.

2.1.3: Incubation periods

The following incubation periods were applied: 1, 120, and 240 days. The samples for each soil type were stored in boxes and placed randomly in a climatic room where they were incubated at a temperature of 20 ^0C (+ or - 2 ^0C). Each treatment combination was replicated three times. After each incubation period a set of 75 samples of each soil type were allowed to air dry before commencing the successive DMT-HFO-P extractions.

2.1.4: Successive DMT-HFO-P extractions

At the end of each incubation period a set of treated samples were air-dried and then subjected to successive DMT–HFO P extractions for 1, 7, 14, 28, and 56 days as described in Chapter 2 (Section 3.2.6). This was done to determine the total DMT–HFO P extractable from each incubation period. To perform the P extractions, the DMT–HFO tubes were placed in wide necked plastic bottles with 80 cm^3 of a 2 $mol.dm^{-3}$ of $CaCl_2$ and 0.3 $mol.dm^{-3}$ of KCl solution as supporting electrolytes and 1gm of soil. These samples were then gently shaken (horizontally) for 1, 7, 14, 28, and 56 days. The tubes were replaced with new ones after every 14 days.

2.2: Soil analyses

2.2.1: Sequential P extractions and analyses

After each DMT–HFO-P extraction time, the soil samples from the different incubation periods were sequentially extracted with 0.5M $NaHCO_3$, 0.1M

NaOH, 1M HCl, conc. HCl, and conc. H_2SO_4 + H_2O_2 according to the modified method of Tiessen and Moir (1993) as described in Chapter 2.

2.3: Phosphorus determinations

The P concentrations were determined according to the Murphy Riley (1962) method as described (Section 3.2.4) in Chapter 2.

2.4: Statistical Analysis

The data from the experiments were analysed statistically using a "Genstat 5 (1995) computer programme. The programme involved the analysis of variance (ANOVA) to determine whether there were any statistical differences between or among the treatments and their interactions. The least significant differences (LSDs) were determined by the LSD (Fisher) tests at 5 % confidence level. The correlation coefficients as well as the regression equations were determined that described the responses to the treatments. The graphs for the extracted P and percent P recovered are presented as smooth curves. They were constructed through different regression fits using 'Microsoft Excel' (1995) programmes (linear: $y = mx + b$; logarithmic: $y = c\ln x + b$; polynomial: $y = b + c_1x + c_2x^2$; exponential: $y = ce^{bx}$; and power: $y = cx^b$) to produce the best fits for each set of data. The graphs were accompanied by regression equations and the R^2 values.

Graphs for the desorption rates are also presented as smooth curves but constructed using derivatives of the different regression fits of the extracted P data with 'Microsoft Excel' (1995) programmes: linear derivatives: $dy = b.dx$; logarithmic derivatives: $dy = m.n.x^{m-1}dx$; and power derivatives: $dy = a.x^{-1}.dx$. The percentages of the applied P recovered in each pool were calculated as: % P recovered = $(Px - Po)/P1*100$; where Px was P in the xth fraction of the P treatment, and Po was P in the oth fraction of the initial no P (P0) treatment, while P1 was the applied P level of the xth fraction.

RESULTS AND DISCUSSION

1. Chemical, physical, and mineralogical characteristics of Rustenburg and Loskop soils

Some selected properties of the two soils studied are shown in Table 1, Chapter 2.

2. The effects of the applied P, incubation periods, and the successive DMT-HFO-P extractions on the P transformations and contributions of the different P pools to the labile P

The successive DMT-HFO extraction procedure used is a part of the sequential P-extractions of soils that were summarized in the flow chart in Figure 1 of Chapter 2. The results of this treatment are presented in Tables 1-3 showing the changes with added P and incubation periods, while Tables 4-18 show the redistributions as fractions of the total soil P pool. The details are presented in Appendices II Nos. 1-24.

According to the ANOVA tables there were very significant responses ($P = 0.01$) in the successive DMT-HFO extracted P and the sequentially extracted P, due to added P and incubation time (Appendices II Nos. 1-24).

Figures 1–18 and 1.1-18.1 are presented as smooth curves constructed through regression equation fits and Figures 1.2-18.2 are from the derivatives of the regression equation fits. The data from the extracts were fitted to 'Microsoft Excel' (1995) programme's linear, logarithmic, and power, functions to produce the best fits for each set of data. The P extractions data fitted to regression equations and the R^2 values indicated very good correlations between treatments and P extractions in most cases.

RUSTENBURG: Table 1a: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 1 day of incubation for Rustenburg soil

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P,	3.22	6.24	7.77	10.70	12.18	7.50	11.93	13.97	24.47	28.50	17.92	21.00	26.73	31.77	38.75	26.57	35.72	45.18	52.68	65.00	46.18	61.50	72.85	81.23	96.77
% P recovered						17.12	22.76	24.60	55.08	65.28	29.40	29.52	37.92	42.14	53.14	23.35	29.48	37.41	41.96	52.82	21.48	27.63	32.54	35.27	42.30
HCO_3-P,	7.00	6.50	5.30	4.30	2.77	14.77	11.47	9.83	5.10	3.65	20.80	18.83	12.63	11.60	8.80	33.40	27.13	22.17	16.23	12.00	69.80	48.27	45.17	38.00	27.33
% P recovered						31.08	19.88	18.12	3.20	3.52	27.60	24.66	14.66	14.60	12.06	26.40	20.63	16.87	11.93	9.23	31.40	20.89	19.94	16.85	12.28
HCO_3-P_o	11.50	3.50	1.97	1.37	1.13	11.60	4.70	4.40	3.23	2.22	12.27	5.50	4.20	3.13	2.40	12.50	7.77	6.50	5.17	3.87	13.53	9.37	7.40	6.40	5.27
% P recovered						0.40	4.80	9.72	7.44	4.36	1.54	4.00	4.48	3.52	2.54	1.00	4.27	4.53	3.80	2.74	1.02	2.94	2.72	2.52	2.07
OH-P,	30.13	22.90	18.58	14.77	10.77	32.80	24.43	21.33	18.30	11.80	41.70	27.00	23.33	21.77	14.67	56.40	42.23	34.83	28.33	22.77	90.47	65.80	58.00	48.30	42.27
% P recovered						10.68	6.12	11.00	14.12	4.12	23.14	8.20	9.50	14.00	7.80	26.27	19.33	16.25	13.56	12.00	30.17	21.45	19.71	16.77	15.75
OH-P_o	12.97	9.63	8.55	7.00	6.10	13.17	10.90	9.33	8.00	7.53	14.03	11.67	10.00	9.53	9.00	14.80	12.90	11.50	10.00	9.50	15.30	14.13	13.17	12.53	11.83
% P recovered						0.80	5.08	3.12	4.00	5.72	2.12	4.08	2.90	5.06	5.60	1.83	3.27	2.95	3.00	3.40	1.17	2.25	2.31	2.77	2.87
D/HCl-P,	8.43	5.95	5.20	5.10	5.00	10.73	8.00	7.75	7.07	6.60	13.53	10.33	9.40	9.20	8.57	15.50	13.80	12.80	11.50	10.87	20.62	17.25	14.70	14.27	13.23
% P recovered						9.20	8.20	10.20	7.88	6.40	10.20	8.76	8.40	8.20	7.14	7.07	7.85	7.60	6.40	5.67	6.10	5.65	4.75	4.59	4.12
C/HCl-P,	48.33	41.27	40.53	38.60	35.77	50.60	43.67	44.60	40.20	37.07	51.20	45.53	44.53	41.33	38.33	52.00	48.53	46.80	43.60	42.47	54.67	54.20	53.53	52.67	49.87
% P recovered						9.08	9.60	16.28	6.40	5.20	5.74	8.52	8.00	5.46	5.12	3.67	7.26	6.27	5.00	6.70	3.17	6.47	6.50	7.04	7.05
C/HCl-P_o	7.00	5.47	4.50	4.00	3.27	7.30	5.67	5.00	4.40	3.47	8.20	7.13	6.00	5.50	4.83	8.67	7.47	6.00	6.07	5.28	9.70	7.90	7.60	6.50	6.13
% P recovered						1.20	0.80	2.00	1.60	0.60	2.40	3.32	3.00	3.00	3.12	1.67	2.00	1.50	2.07	2.01	1.35	1.22	1.55	1.25	1.43
H_2SO_4-P,	56.67	39.33	36.03	30.42	26.08	59.92	44.50	38.17	31.63	28.25	61.72	47.67	43.40	37.67	31.20	67.83	51.75	50.77	43.25	36.50	69.83	59.67	55.93	53.83	46.90
% P recovered						13.00	20.88	8.56	5.64	8.68	10.10	16.68	14.74	14.50	10.24	11.16	12.42	14.74	12.83	10.42	6.58	10.17	9.95	11.71	10.41
Total P extracted	185.25	140.79	128.43	116.26	103.07	208.39	165.27	154.38	142.60	129.09	241.37	194.66	180.22	171.50	156.55	287.67	247.30	236.55	216.83	208.26	390.10	338.09	328.35	313.73	299.60
Total % P recovered						92.56	97.92	103.80	105.36	104.08	112.24	107.74	103.58	110.48	106.96	102.42	106.51	108.12	100.57	105.19	102.43	98.65	99.96	98.74	98.27

LOSKOP: Table 1b: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 1 day of incubation for Loskop soil.

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P,	6.30	8.42	10.50	12.75	14.70	13.93	20.50	24.03	32.25	33.97	27.38	30.17	35.58	40.35	45.65	46.68	53.67	60.05	71.05	77.53	67.22	80.17	92.80	102.50	115.87
% P recovered						30.52	48.32	54.12	78.00	77.08	42.16	43.50	50.16	55.20	61.90	40.38	45.25	49.55	56.30	62.83	30.46	35.88	41.15	44.88	50.59
HCO_3-P,	12.27	12.00	9.07	7.47	5.80	18.87	14.43	12.00	8.57	7.57	25.00	22.77	16.50	13.27	10.17	42.73	33.13	28.30	20.50	15.33	78.00	58.77	50.47	42.53	31.83
% P recovered						26.40	9.72	11.72	4.40	7.08	25.48	21.54	14.86	11.60	8.74	30.46	21.13	19.23	13.03	9.53	32.87	23.39	20.70	17.53	13.02
HCO_3-P_o	7.07	4.63	3.13	2.87	1.53	8.00	5.70	4.27	2.97	1.77	8.47	4.90	4.50	3.07	2.50	9.93	7.67	6.57	5.50	4.00	10.80	8.00	7.20	6.53	5.00
% P recovered						3.72	4.28	4.56	0.40	0.96	2.80	0.54	2.74	0.40	1.94	2.86	3.24	3.44	2.63	2.47	1.87	1.69	2.04	1.83	1.74
OH-P,	25.33	20.83	19.45	15.93	13.40	28.13	24.13	22.07	18.13	14.72	31.77	28.30	25.83	22.67	20.82	37.20	32.90	29.50	25.77	22.00	65.93	62.70	56.07	49.80	39.45
% P recovered						11.20	13.20	10.48	8.60	5.28	12.88	14.94	12.76	13.48	14.84	11.87	12.07	10.05	9.84	8.80	20.30	20.94	18.31	16.94	13.03
OH-P_o	9.20	7.10	6.35	5.00	4.77	11.93	9.47	8.97	6.53	6.62	12.43	10.30	9.57	8.27	7.42	13.53	11.30	10.80	9.50	8.00	15.13	13.83	11.47	10.80	10.02
% P recovered						10.92	9.48	10.48	6.12	7.40	6.46	6.40	6.44	6.54	5.30	4.33	4.20	4.45	4.50	3.23	2.97	3.37	2.56	2.90	2.63
D/HCl-P,	6.13	4.87	4.72	4.50	4.30	7.90	6.80	6.47	5.32	4.93	8.77	6.93	6.67	6.00	5.42	12.80	9.20	8.50	7.80	7.00	14.07	12.33	11.00	9.67	9.10
% P recovered						7.08	7.72	7.00	3.28	2.52	5.28	4.12	3.90	3.00	2.24	6.67	4.33	3.78	3.30	2.70	3.97	3.73	3.14	2.59	2.40
C/HCl-P,	31.10	29.27	27.87	26.20	25.87	32.53	30.33	28.80	27.33	26.27	33.67	32.60	30.53	28.93	27.93	35.53	34.60	33.60	31.27	30.60	40.53	39.60	37.93	36.27	34.77
% P recovered						5.72	4.24	3.72	4.52	1.60	5.14	6.66	5.32	5.48	4.12	4.43	5.33	5.73	5.07	4.73	4.72	5.17	5.03	5.04	4.45
C/HCl-P_o	5.07	3.93	2.80	2.40	2.23	5.97	4.33	3.07	2.67	2.40	6.17	4.73	3.90	3.50	3.20	6.50	5.35	4.80	4.20	3.87	7.47	6.50	6.00	5.00	4.57
% P recovered						3.60	1.60	1.08	1.08	0.68	2.20	1.60	2.20	2.20	1.94	1.43	1.42	2.00	1.60	1.64	1.20	1.29	1.60	1.30	1.17
H_2SO_4-P,	45.75	34.33	32.87	25.75	23.78	46.92	35.67	33.63	25.95	24.50	48.17	36.33	34.87	28.42	25.68	50.67	39.67	37.60	33.58	29.58	53.87	44.00	43.90	40.60	37.22
% P recovered						4.68	5.36	3.04	0.80	2.88	4.84	4.00	4.00	5.34	3.60	4.92	5.34	4.73	7.83	5.80	4.06	4.84	5.52	7.43	6.72
Total P extracted	148.22	125.38	116.76	102.87	96.38	174.18	151.36	143.31	129.72	122.75	201.83	177.03	167.95	154.48	146.79	255.57	227.69	219.72	209.17	197.91	353.02	325.90	316.84	303.70	287.83
Total % P recovered						103.84	103.92	106.20	107.40	105.48	107.22	103.30	102.38	103.22	104.82	107.35	102.31	102.96	106.30	101.53	102.40	100.26	100.04	100.42	95.73

RUSTENBURG: Table 2a: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 120 days of incubation for Rustenburg soil.

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P_i	3.25	5.05	6.33	7.15	10.42	3.52	7.17	12.28	17.33	23.52	6.97	12.83	21.12	25.78	34.47	11.38	21.52	32.53	42.25	52.83	21.63	36.38	45.30	60.02	74.73
% P recovered						1.08	8.48	23.80	40.72	52.40	7.44	15.56	29.58	37.26	48.10	8.13	16.47	26.20	35.10	42.41	9.19	15.67	19.49	26.44	32.16
HCO_3-P_i	3.97	3.27	3.07	2.93	2.60	6.22	4.47	4.10	3.20	2.93	9.50	7.60	6.10	5.20	5.33	14.58	10.93	10.30	8.93	8.20	23.02	19.77	14.97	12.20	11.27
% P recovered						9.00	4.80	4.12	1.08	1.32	11.08	8.66	6.08	4.54	5.46	10.61	7.66	7.23	6.00	5.60	9.53	8.25	5.95	4.64	4.34
HCO_3-P_o	9.03	7.33	6.50	5.00	4.28	10.45	8.35	6.90	5.97	4.80	12.33	9.97	8.47	7.63	6.50	14.92	11.57	9.77	8.47	7.63	17.25	14.03	12.47	10.13	8.73
% P recovered						5.68	4.08	1.60	3.88	2.08	6.60	5.28	3.94	5.26	4.44	5.89	4.24	3.27	3.47	3.35	4.11	3.35	2.99	2.57	2.23
OH-P_i	44.83	35.87	30.83	25.47	23.23	57.83	43.27	38.10	28.80	25.43	62.10	47.60	43.90	34.73	31.03	74.17	59.05	50.90	43.93	41.83	100.67	75.87	69.10	64.97	56.40
% P recovered						52.00	29.60	29.08	13.32	8.80	34.54	23.48	26.14	18.52	15.60	29.34	23.18	20.07	18.46	18.60	27.92	20.00	19.14	19.75	16.59
OH-P_o	12.37	10.28	9.37	8.07	6.83	13.63	12.37	11.07	9.93	8.50	14.23	13.10	12.30	11.40	10.23	18.60	15.88	13.30	13.00	11.50	25.20	20.33	18.23	16.10	14.60
% P recovered						5.04	8.36	6.80	7.44	6.68	3.72	5.64	5.86	6.86	6.80	6.23	5.60	3.93	4.93	4.67	6.42	5.03	4.43	4.02	3.89
D/HCl-P_i	7.72	6.13	6.00	5.53	4.97	11.92	9.43	8.80	7.92	6.92	13.07	12.50	10.43	9.23	8.80	16.87	15.00	14.43	12.53	11.87	28.93	24.50	22.67	20.03	18.13
% P recovered						16.80	13.20	11.20	9.56	7.80	10.70	12.74	8.86	7.40	7.66	9.15	8.87	8.43	7.00	8.90	10.61	9.19	8.34	7.25	6.58
C/HCl-P_i	51.27	43.33	41.77	38.93	35.83	52.53	46.27	43.20	41.53	37.33	55.40	49.00	45.93	42.87	40.53	61.17	54.67	53.40	47.00	45.87	76.60	73.87	71.20	68.20	65.93
% P recovered						5.04	11.76	5.72	10.40	6.00	8.26	11.34	8.32	7.88	9.40	9.90	11.34	11.63	8.07	10.04	12.67	15.27	14.72	14.64	15.05
C/HCl-P_o	7.07	4.73	4.55	3.63	2.57	7.60	6.03	5.17	4.23	3.53	8.53	7.23	6.27	6.03	5.07	10.10	8.27	7.27	6.33	6.03	12.37	9.83	9.13	8.00	6.67
% P recovered						2.12	5.20	2.48	2.40	3.84	2.92	5.00	3.44	4.80	5.00	3.03	3.54	2.72	2.70	3.46	2.65	2.55	2.29	2.19	2.05
H_2SO_4-P_i	58.42	45.67	40.75	33.88	31.33	60.92	49.75	45.13	38.02	33.92	68.67	54.58	49.77	44.30	36.52	79.08	67.90	61.45	50.98	45.60	92.67	85.80	77.50	70.23	66.42
% P recovered						10.00	16.32	17.52	16.56	10.36	20.50	17.82	18.04	20.84	10.38	20.66	22.23	20.70	17.10	14.27	17.13	20.07	18.38	18.18	17.55
Total P extracted	197.93	161.66	149.17	130.59	122.06	224.62	187.11	174.75	156.93	146.88	250.80	214.41	204.29	187.17	178.48	300.87	264.79	253.35	233.42	231.36	398.34	360.38	340.57	329.88	322.88
Total % P recovered						106.76	101.80	102.32	105.36	99.28	105.74	105.50	110.24	113.16	112.64	102.94	103.13	104.18	102.83	109.30	100.21	99.36	95.70	99.65	100.41

LOSKOP: Table 2b: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 120 days of incubation for Loskop soil.

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P_i	5.22	6.72	7.72	9.30	12.20	12.63	16.77	22.22	26.88	32.87	16.72	22.53	26.52	32.40	42.03	24.27	32.87	43.42	58.53	71.67	39.63	54.37	70.17	88.43	108.50
% P recovered						29.64	40.20	58.00	70.32	82.88	23.00	31.62	37.60	46.20	59.66	19.05	26.15	35.70	49.23	59.47	17.21	23.83	31.23	39.57	48.15
HCO_3-P_i	11.27	10.47	7.80	5.90	3.27	13.57	11.00	9.53	7.28	4.23	20.87	15.33	13.00	10.97	8.10	35.47	24.77	20.13	15.07	11.93	56.33	46.10	40.93	32.70	28.07
% P recovered						9.20	2.12	6.92	5.52	3.84	19.20	9.72	10.40	10.14	9.66	24.20	14.30	12.33	9.17	8.66	22.53	17.82	16.57	13.40	12.40
HCO_3-P_o	6.93	4.03	3.53	2.00	1.50	11.17	6.40	5.58	3.00	2.17	11.67	6.93	5.33	4.03	3.00	13.20	8.77	6.53	4.80	3.67	13.85	10.90	8.33	5.97	4.80
% P recovered						16.96	9.48	8.20	4.00	2.68	9.48	5.80	3.60	4.06	3.00	8.27	4.74	3.00	2.80	2.17	3.36	3.44	2.40	1.99	1.65
OH-P_i	29.13	25.13	21.43	19.27	17.57	33.27	27.67	23.60	21.10	18.75	36.93	32.27	29.97	26.93	22.57	47.00	40.63	38.43	33.67	29.25	78.80	67.43	59.77	51.07	46.20
% P recovered						16.56	10.16	8.68	7.32	4.72	15.60	14.28	17.08	15.32	10.00	17.87	15.50	17.00	14.40	11.68	24.74	21.15	19.17	15.90	14.32
OH-P_o	8.13	6.07	4.97	4.33	2.83	10.20	8.20	6.13	5.37	4.32	11.40	9.07	8.50	6.53	5.37	14.27	12.17	10.83	9.13	8.35	17.07	14.83	12.80	11.60	10.40
% P recovered						8.28	8.52	4.64	4.18	5.96	6.54	6.00	7.08	4.40	5.08	6.14	6.10	5.86	4.80	5.52	4.47	4.36	3.92	3.64	3.79
D/HCl-P_i	6.40	5.77	5.55	5.33	4.47	9.47	8.27	7.10	6.13	5.27	10.00	9.87	8.93	7.60	7.17	14.80	12.73	10.53	9.47	8.28	18.93	14.27	12.20	11.60	10.17
% P recovered						12.28	10.00	6.20	3.20	3.20	7.20	8.20	6.76	4.54	5.40	8.40	6.96	4.98	4.14	3.81	6.27	4.25	3.33	3.14	2.85
C/HCl-P_i	32.60	30.00	29.67	27.20	26.13	34.67	31.33	30.00	29.00	26.60	36.87	34.47	32.27	31.53	28.33	40.13	38.33	37.67	35.93	31.93	50.27	49.67	48.67	46.33	44.60
% P recovered						8.28	5.32	1.32	7.20	1.88	8.54	8.94	5.20	8.66	4.40	7.53	8.33	8.00	8.73	5.80	8.84	9.84	9.50	9.57	9.24
C/HCl-P_o	5.40	4.33	4.00	3.67	3.53	6.27	5.50	5.08	4.50	4.00	7.63	7.20	6.80	5.60	5.00	10.57	9.00	8.00	6.93	6.07	13.48	11.00	9.67	8.00	7.00
% P recovered						3.48	4.68	4.32	3.32	1.88	4.48	5.74	5.80	3.88	2.94	5.17	4.87	4.00	3.26	2.54	4.04	3.34	2.84	2.17	1.74
H_2SO_4-P_i	47.00	35.17	30.75	28.67	24.67	49.00	38.80	33.00	30.08	25.83	51.33	41.50	38.25	31.92	28.00	55.67	47.50	40.33	34.42	30.50	64.83	57.00	53.00	47.67	42.33
% P recovered						8.00	14.52	9.00	5.64	4.64	8.66	12.68	15.00	8.50	6.66	8.67	12.33	9.58	5.75	5.83	8.92	10.92	11.13	9.60	8.83
Total P extracted	152.08	127.69	115.42	105.67	96.17	180.25	153.94	142.24	133.34	124.04	203.42	179.17	169.57	157.51	149.57	255.38	226.77	215.87	207.95	201.65	352.79	325.57	315.54	303.57	302.07
Total % P recovered						112.68	105.00	107.28	110.68	111.48	102.68	102.96	108.30	103.68	106.60	103.30	99.08	100.45	102.28	105.48	100.36	98.94	100.06	98.85	102.95

RUSTENBURG: Table 3a: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 240 days of incubation for Rustenburg soil.

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P_i	2.85	4.50	5.53	6.87	8.92	4.30	5.70	7.25	9.70	12.40	5.27	10.92	15.25	20.93	25.60	8.17	15.00	19.85	27.47	36.13	14.62	23.13	31.50	42.08	53.63
% P recovered						5.80	4.80	6.88	11.32	13.92	4.84	12.84	19.44	28.12	33.36	5.32	10.50	14.32	20.80	27.21	5.89	9.32	12.99	17.61	22.36
HCO_3-P_i	2.80	2.77	2.72	2.67	1.87	5.27	4.33	3.33	3.00	2.30	7.97	7.00	6.55	5.50	4.77	10.73	9.67	8.53	7.60	6.80	18.80	14.33	13.83	11.57	9.13
% P recovered						9.88	6.24	2.44	1.32	1.72	10.34	8.46	7.66	5.66	5.80	7.83	6.90	5.81	4.93	4.93	8.00	5.76	5.56	4.45	3.63
HCO_3-P_o	6.90	5.70	4.00	3.87	2.50	9.40	7.00	5.67	4.43	3.80	11.60	8.88	6.78	5.50	4.40	12.27	10.33	9.30	7.53	6.67	14.20	11.67	10.67	9.50	8.18
% P recovered						10.00	5.20	6.68	2.24	5.20	9.40	6.36	5.56	3.26	3.80	5.37	4.63	5.30	3.66	4.17	3.65	2.99	3.34	2.82	2.64
OH-P_i	55.17	36.50	31.33	26.20	21.33	57.98	40.35	34.92	30.77	25.27	65.67	46.75	42.30	34.60	30.23	74.00	59.50	55.38	50.00	43.67	106.17	87.97	79.25	69.00	59.27
% P recovered						11.24	15.40	14.36	18.28	15.76	21.00	20.50	21.94	18.80	17.80	18.83	23.00	24.05	23.80	22.34	25.50	25.74	23.96	21.40	18.97
OH-P_o	10.75	9.23	8.20	7.92	6.80	12.82	10.95	10.62	9.77	8.43	13.63	12.75	11.30	10.50	9.57	15.33	13.45	12.15	11.47	10.50	17.80	15.50	13.68	12.93	11.00
% P recovered						8.28	6.88	9.68	7.40	6.52	5.76	7.04	6.20	5.16	5.54	4.58	4.22	3.95	3.55	3.70	3.53	3.14	2.74	2.51	2.10
D/HCl-P_i	9.87	7.80	7.08	6.20	5.40	14.17	11.43	9.98	9.33	7.77	18.33	14.17	12.72	10.30	8.80	22.27	18.40	14.95	12.53	11.67	27.53	20.52	18.78	16.53	14.30
% P recovered						17.20	14.52	11.80	12.52	9.48	16.92	12.74	11.28	8.20	6.80	12.40	8.60	7.87	6.33	6.27	8.83	8.36	5.85	5.17	4.45
C/HCl-P_i	58.70	50.00	46.60	40.60	38.27	60.00	53.90	49.37	46.67	42.27	64.40	56.07	51.33	49.27	45.00	76.30	62.93	59.00	53.00	48.00	95.80	86.10	81.60	76.67	71.67
% P recovered						5.20	15.80	11.08	24.28	16.00	11.40	12.14	9.46	17.34	13.46	17.60	12.93	12.40	12.40	9.73	18.55	18.05	17.50	18.04	16.70
C/HCl-P_o	7.77	5.67	4.50	3.97	3.27	8.52	7.03	6.00	5.33	4.23	9.70	8.57	7.57	6.73	5.93	12.35	10.37	9.47	8.33	7.27	13.53	11.77	10.40	9.60	9.03
% P recovered						3.00	5.44	6.00	5.44	3.84	3.86	5.80	6.14	5.52	5.32	4.58	4.70	4.97	4.36	4.00	2.88	3.05	2.95	2.82	2.88
H_2SO_4-P	60.83	50.67	48.17	40.40	35.25	68.13	58.83	56.92	48.33	43.33	76.25	64.67	59.42	52.73	47.75	91.00	78.33	71.83	64.33	58.92	116.13	103.25	96.35	86.67	86.00
% P recovered						29.20	32.64	35.00	31.72	32.32	30.84	28.00	22.50	24.66	25.00	30.17	27.66	23.66	23.93	23.67	27.65	26.29	24.09	24.14	25.38
Total P extracted	215.64	172.84	158.13	138.70	123.61	240.59	199.52	184.06	167.33	149.80	272.82	229.78	213.22	196.06	182.05	322.42	275.98	260.46	242.26	229.63	424.58	374.24	356.06	336.55	322.21
Total % P recovered						99.80	106.72	103.72	114.52	104.76	114.36	113.68	110.18	114.72	116.88	108.78	103.14	102.33	103.56	106.02	104.47	100.70	98.97	98.93	99.30

LOSKOP: Table 3b: The effects of successive DMT-HFO-P extractions on the P contents of different P pools as influenced by different P application rates after 240 days of incubation for Loskop soil.

Added P			0					25					50					100					200		
Successive Extractions (days)	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56	1	7	14	28	56
HFO-P_i	4.13	5.82	6.50	8.55	12.17	12.13	14.80	17.67	24.17	27.75	13.43	20.85	25.83	30.50	38.58	18.73	33.43	40.33	52.50	63.17	35.20	49.63	60.50	76.17	92.00
% P recovered						32.00	35.92	44.88	62.48	62.32	16.80	30.06	38.66	43.90	52.82	14.60	27.61	33.63	43.95	51.00	15.54	21.91	27.00	33.61	39.92
HCO_3-P_i	9.60	7.77	6.50	4.33	3.53	12.43	9.67	8.33	6.83	3.63	14.13	12.93	10.67	7.53	5.83	22.10	16.55	13.77	11.07	8.53	44.83	32.55	27.43	21.93	17.23
% P recovered						11.32	7.60	7.32	10.00	0.40	9.08	10.32	8.34	6.40	4.60	12.50	8.78	7.27	6.74	5.00	17.62	12.39	10.47	8.80	6.85
HCO_3-P_o	6.00	4.63	3.43	2.07	2.05	8.43	7.27	6.40	4.63	3.50	10.93	8.37	7.07	5.33	4.77	11.10	9.18	8.07	7.40	6.00	12.77	11.32	10.20	8.63	7.77
% P recovered						9.72	10.56	11.88	10.24	5.80	9.86	7.48	7.28	6.52	5.44	5.10	4.55	4.64	5.33	3.95	3.39	3.35	3.39	3.28	2.86
OH-P_i	32.93	28.87	25.32	21.60	19.30	35.10	32.27	28.98	23.45	20.60	41.10	35.00	31.75	28.50	24.63	56.30	48.53	44.00	36.78	32.63	86.53	73.20	63.53	54.07	46.83
% P recovered						8.68	13.60	14.64	7.40	5.20	16.34	12.26	12.86	13.80	10.66	23.37	19.66	18.88	15.18	13.33	26.80	22.17	19.11	16.24	13.77
OH-P_o	7.11	6.93	6.22	5.00	4.70	9.17	8.27	7.88	7.15	6.03	11.43	10.57	8.78	7.83	7.37	14.40	12.40	10.67	8.88	8.30	15.93	14.37	12.07	11.53	10.83
% P recovered						8.24	5.36	6.64	8.60	5.32	8.64	7.28	5.12	5.66	5.34	7.29	5.47	4.45	3.88	3.80	4.41	3.72	2.93	3.27	3.07
D/HCl-P_i	6.65	6.30	5.60	5.50	5.30	9.13	7.63	7.47	6.93	6.30	12.27	11.00	9.37	8.37	8.27	16.02	13.40	12.20	11.13	10.60	19.40	15.20	14.13	13.00	12.73
% P recovered						9.92	5.32	7.48	5.72	4.00	11.24	9.40	7.54	5.74	5.94	9.37	7.10	6.60	5.63	5.30	6.38	4.45	4.27	3.75	3.72
C/HCl-P_i	38.00	32.67	31.93	29.67	27.27	39.27	35.33	32.93	30.93	28.47	41.93	38.27	34.93	32.60	30.00	48.47	43.60	39.93	35.93	33.67	59.27	58.00	56.67	52.53	50.33
% P recovered						5.08	10.64	4.00	5.04	4.80	7.86	11.20	6.00	5.86	5.46	10.47	10.93	8.00	6.26	6.40	10.64	12.67	12.37	11.43	11.53
C/HCl-P_o	6.40	4.93	4.27	3.20	2.67	7.07	6.00	5.67	4.50	4.13	10.93	8.33	7.33	6.40	5.33	12.20	10.07	8.73	7.33	6.33	12.47	10.60	9.27	8.47	8.27
% P recovered						2.68	4.28	5.60	5.20	5.84	9.06	6.80	6.12	6.40	5.32	5.80	5.14	4.48	4.13	3.66	3.04	2.84	2.50	2.84	2.80
H_2SO_4-P	47.75	41.48	35.00	33.00	30.75	52.00	45.75	37.25	34.00	32.17	56.42	49.67	44.25	38.50	34.17	61.00	54.08	50.67	46.00	40.33	75.33	73.08	68.42	64.83	62.67
% P recovered						17.00	17.08	9.00	4.00	5.68	17.34	16.36	18.50	11.00	6.84	13.25	12.60	15.67	13.00	9.58	13.79	15.80	16.71	15.92	15.98
Total P extracted	158.57	139.40	124.77	112.92	107.74	184.73	166.99	152.58	142.59	132.58	212.57	194.99	179.98	165.56	158.95	260.32	241.24	228.37	217.02	209.56	361.73	337.95	322.22	311.16	308.66
Total % P recovered						104.64	110.36	111.24	118.68	99.36	108.00	111.18	110.42	105.28	102.42	101.75	101.84	103.60	104.10	101.82	101.56	99.28	98.73	99.12	100.46

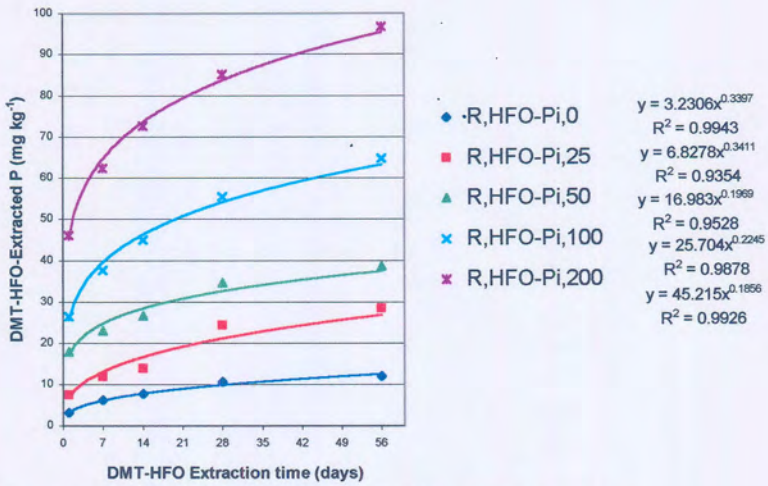

Fig.1a. The effects of the added P on cumulative DMT-HFO extractable P_i after 1 day of incubation of Rustenburg soil

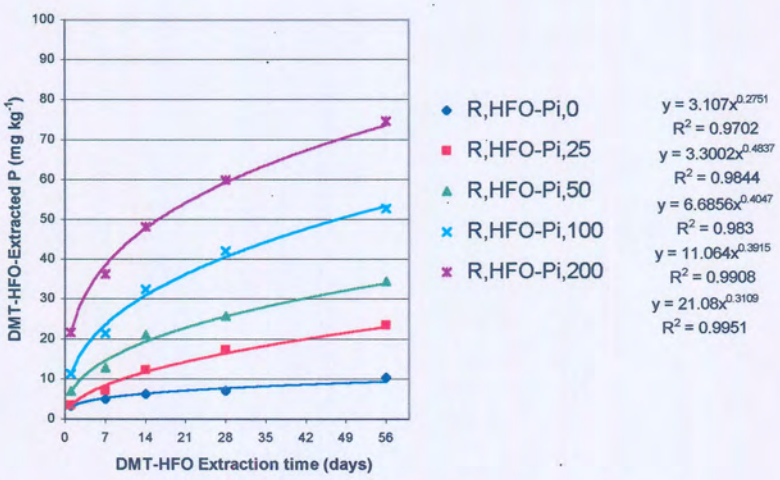

Fig.1b. The effects of the added P on cumulative DMT-HFO extractable P_i after 120 days of incubation of Rustenburg soil

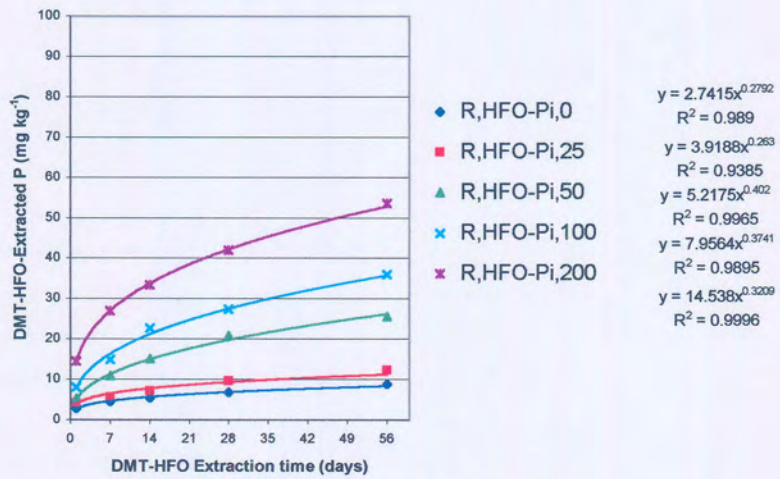

Fig.1c. The effects of the added P on cumulative DMT-HFO extractable P_i after 240 days of incubation of Rustenburg soil

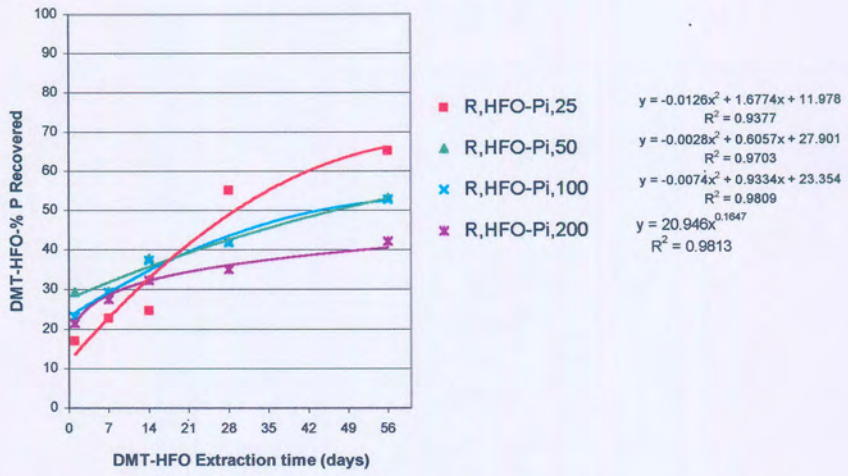

Fig.1.1a. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 1 day of incubation of Rustenburg soil

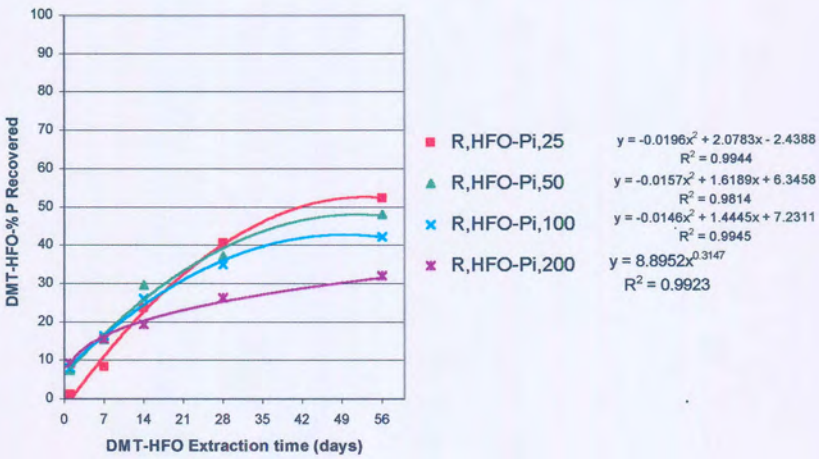

Fig.1.1b. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 120 days of incubation of Rustenburg soil

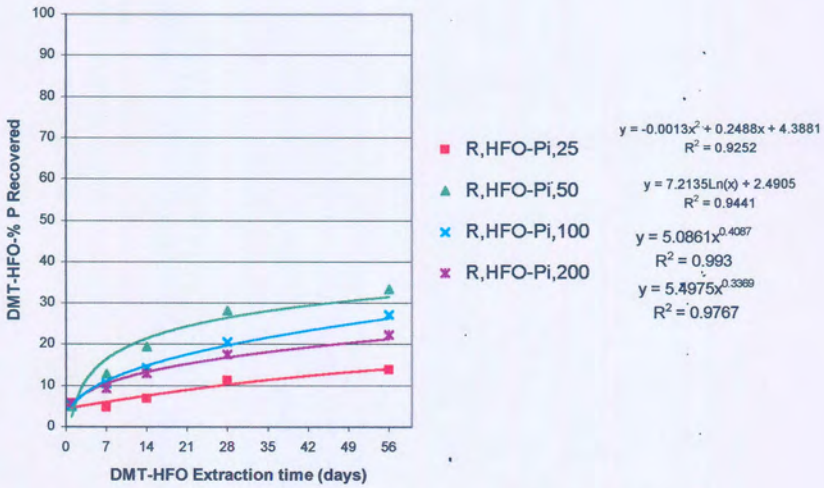

Fig. 1.1c. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 240 days of incubation of Rustenburg soil

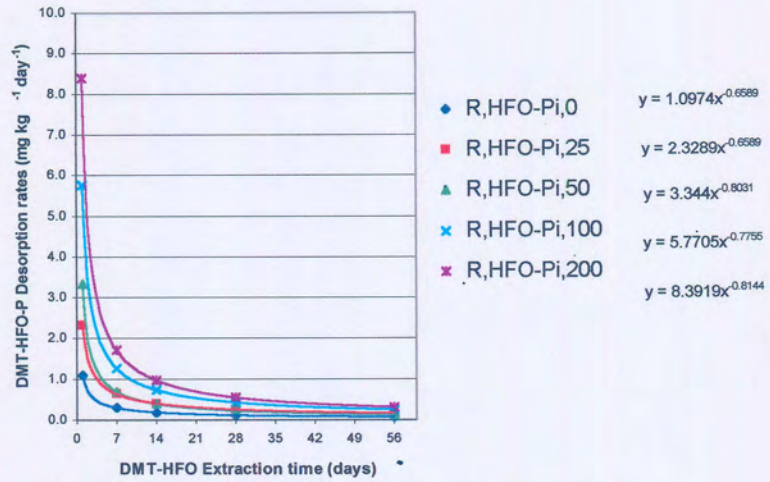

Fig. 1.2a. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 1day of incubation of Rustenburg soil

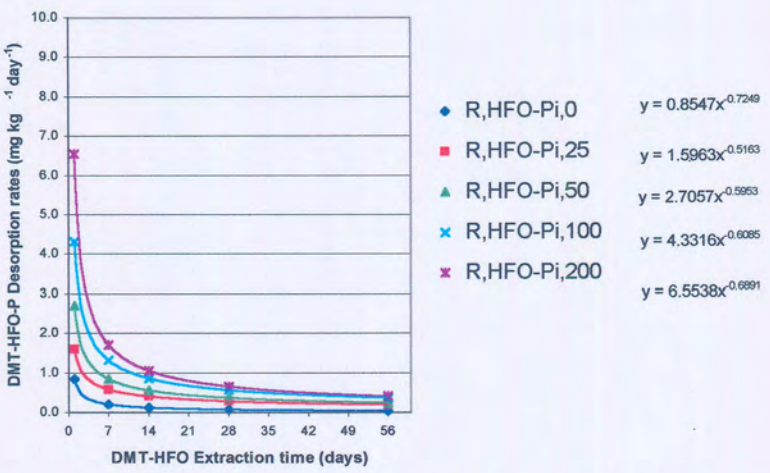

Fig.1.2b. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

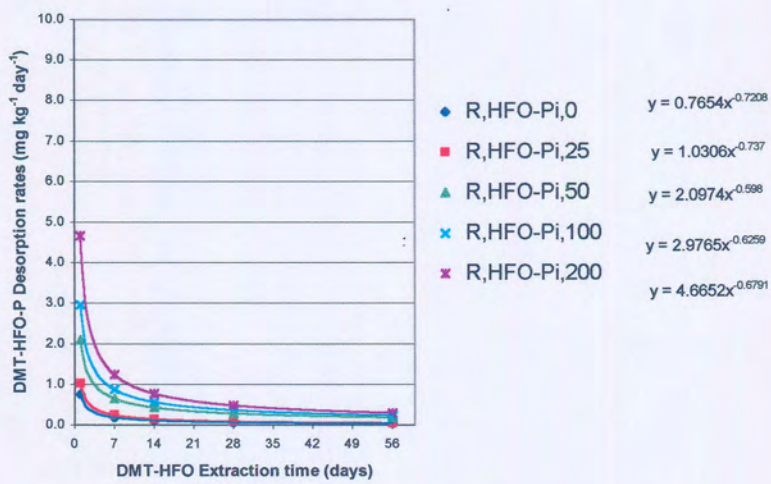

Fig. 1.2c. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

The results of the successive DMT-HFO and sequential P extractions have been discussed and summarized in three groups according to their relative availability to crop plants in the soils:

(a) Plant-available P: consists of solution-P (successive DMT – HFO-P_i extracts) and labile-P (0.5M $NaHCO_3$-P_i and P_o extracts);

(b) Adsorbed P: consists of adsorbed or slowly labile P (0.1M NaOH-P_i and P_o + 1M HCl-P_i extracts); and

(c) Insoluble or occluded and residual P: consisting of occluded and recalcitrant P (conc. HCl-P_i and P_o extracts) and residual or lattice-P (conc. H_2SO_4 + H_2O_2-P_i extracts) (Hedley et al., 1982; Tiessen and Moir, 1993).

2a: The effects of added P and incubation time on the successive DMT- HFO-P extractions from the Rustenburg and Loskop soils

2a: (i). Rustenburg Soil

The DMT-HFO extracted P for different extraction times as influenced by P application rates and incubation periods are presented in Tables 1a-3a (Rustenburg soil) and Figures 1, 1.1 and 1.2. All treatment levels influenced the DMT-HFO extractable P from the different P pools significantly (P = 0.01) according to the ANOVA and LSD (Fisher) values (Appendices II No. 1). Where no P was added the DMT-HFO-extracted P did not change much (3.2–2.8 mg kg^{-1}) with different incubation times. Although the amounts of DMT-HFO extracted P increased with increasing amounts of the added P, the percentage P recovered did not change much. Of importance was the fact that after only one day of incubation less than 30 % was recovered. As the incubation time increased less P was extracted and the percentage P recovered decreased. Here it is important to note that the percent P recoveries were higher for the low P applications compared to the recoveries for the higher P applications. Figures 1a-c illustrating the amount of P extracted over different

periods of extraction time indicates that after 56 days of extractions less P was extracted compared to the Loskop soil (Figs. 2a-c).

The percentage P recovered from the added P (25-200 mg kg^{-1}) after 1 day of the DMT-HFO extraction, decreased from 17.12 and 21.48 % after 1 day of incubation to 5.80 and 5.89 % after 240 days of incubation respectively. The values after 56 days of cumulative DMT-HFO extractions also decreased significantly from 65.28 and 42.30 % after 1 day to 13.92 and 22.36 % after 240 days of incubation respectively from 25-200 mg kg^{-1} added P (Tables 1a-3a; Figs. 1a-c and 1.1a-c). The contributions of DMT-HFO extracts (1-56 days) to the total P pool also reduced from 6.77-24.43 % (1 day) to 2.20-12.30 % after 240 days of incubation (Tables 4a-18a).

The P desorption rates from the samples that received different P applications varied significantly over the different incubation periods (Figs. 1.2a-c). There were significant decreases in the desorption rates after one day of incubation due to different P application rates, which varied from 8.39 mg kg^{-1} day^{-1} at the highest P rate (200 mg kg^{-1}) to only 1.1 mg kg^{-1} where no P was applied. After 240 days of incubation the desorption rates decreased to 4.47 for the highest (200 mg kg^{-1}) application rate and to only 0.77 mg kg^{-1} day^{-1} with no P applied. Of importance is the very significant decreases in desorption rate over the first 14 days of extraction indicating that a fair amount of applied P could be extracted over the first 14 days of extraction with DMT-HFO. For the longer DMT-HFO extraction time (28-56 days) there were very little differences in desorption rates due to different P applications and incubation times and the desorption rates were less than 1 mg kg^{-1} day^{-1} after 1 day and decreased to less than 0.5 mg kg^{-1} day^{-1} after 240 days of incubation.

2a: (ii). Loskop soil

The DMT-HFO extracted P for different extraction times as influenced by P application rates and incubation periods for Loskop soil are presented in Tables 1b-3b and Figures 2, 2.1 and 2.2. Like for the Rustenburg soil all treatment levels

influenced the extractable P from the different P pools significantly (P = 0.01) according to the ANOVA and LSD (Fisher) values (Appendices II No. 13).

As it was for the Rustenburg soil, the amount of P extracted with the DMT-HFO did not change much with different incubation periods (1-240 days) where no P was added (6.30–4.13 mg kg^{-1}). Likewise, although the amount of DMT-HFO extracted P increased with increasing amounts of added P, the percentage P recovered did not change much after 1 day of incubation (31.52-30.46 %). However, there were significant variations with the increasing time of incubation from 120-240 days with the latter reducing by about half the amount between the lowest and highest added P levels (32.00-15.54 % and 62.32-39.92 %) after 1-56 days of extractions respectively. In contrast to the Rustenburg soil up to 40 % of the added P could still be recovered after 1 day of incubation.

But, in general as the incubation time increased, less P was extracted and the percentage P recovered decreased. Here again it is important to note that the percent P recoveries were higher from the low P applications compared to the higher P applications. The differences increased with the extraction time (10-40 %) between 1 and 56 days of extraction. Figures 2a-c and 2.1a-c show that the amount of P extracted and the percent P recovered from different extraction times were more than for the Rustenburg soil and reduced gradually. Thus after 120 days about 80 % of the added P was still recoverable as after 1 day of incubation from 25 mg kg^{-1} added P.

The P desorption rates of the Loskop soil showed similar trends to the Rustenburg soil. However, at the early stages desorption rates were higher than for the Rustenburg soil. Thus up to 7.73 mg kg^{-1} day^{-1} from the 200 mg kg^{-1} added P could still be desorbed after 240 days of incubation and one day of DMT-HFO extraction. The decreases in desorption rates were similar and after 14 days of extractions little changes in desorption rates were evident for longer extraction periods. The changes in desorption rates were reduced to lower than 1 mg P kg^{-1} day^{-1} after 14 days of extraction with DMT-HFO after which the desorption rates were nearly the same for all treatment levels (Figs. 2.2a-c).

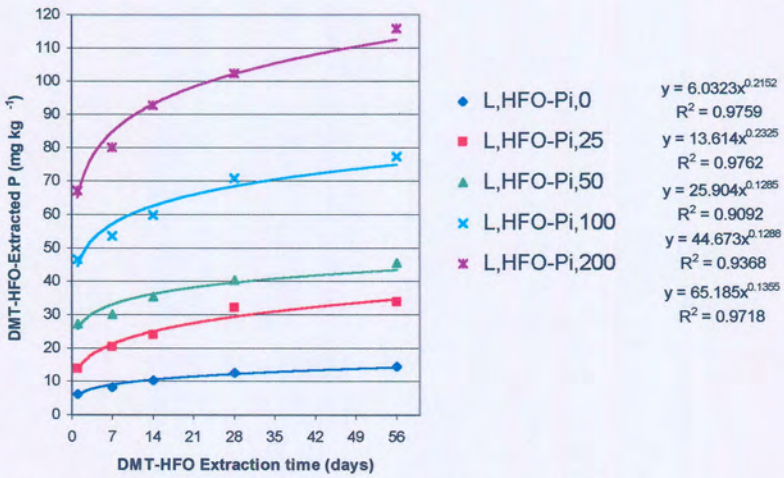

Fig. 2a. The effects of the added P on cumulative DMT-HFO extractable P_i after 1 day of incubation of Loskop soil

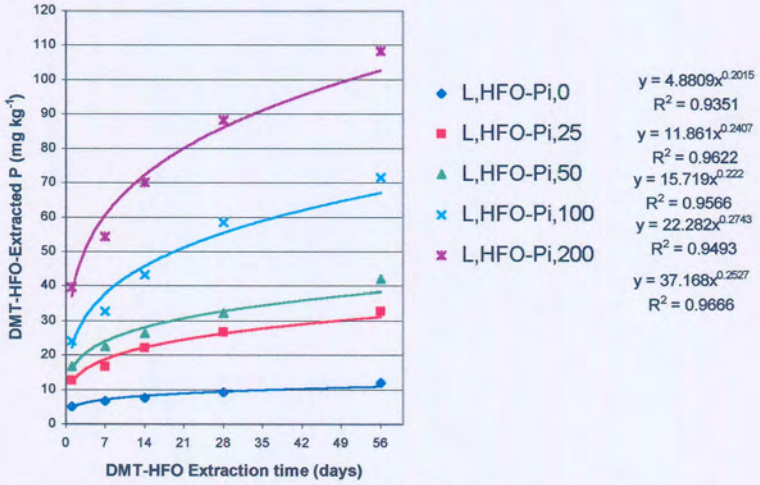

Fig. 2b. The effects of the added P on cumulative DMT-HFO extractable P_i after 120 days of incubation of Loskop soil

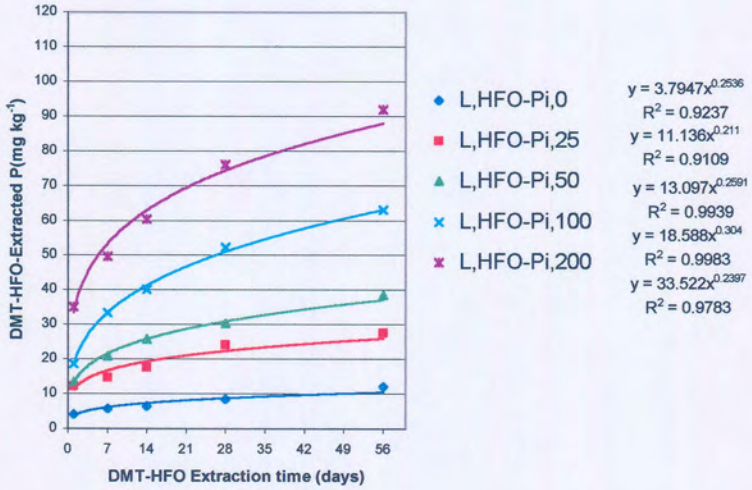

Fig. 2c. The effects of the added P on cumulative DMT-HFO extractable P_i after 240 days of incubation of Loskop soil

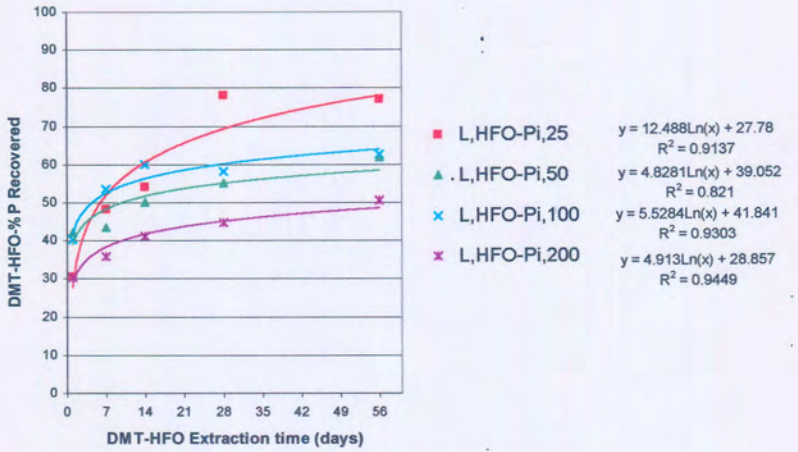

Fig. 2.1a. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 1 day of incubation of Loskop soil

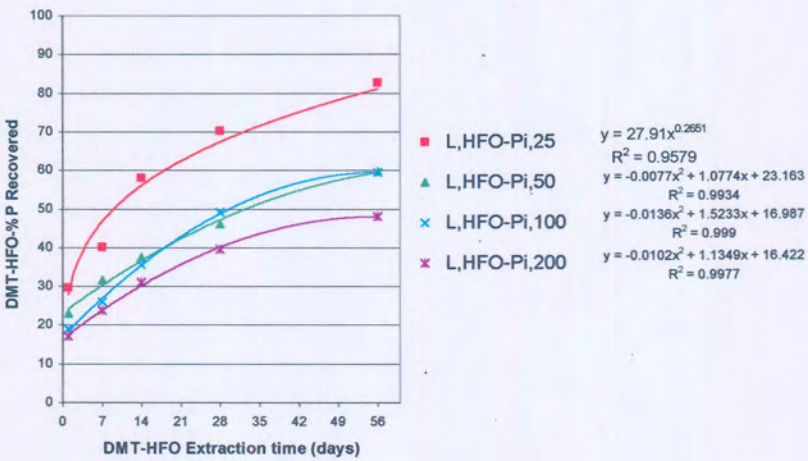

Fig. 2.1b. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 120 days of incubation of Loskop soil

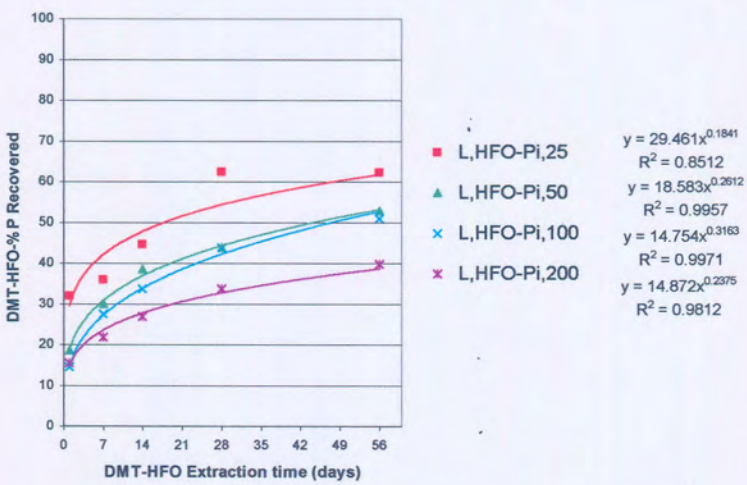

Fig. 2.1c. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 240 days of incubation of Loskop soil

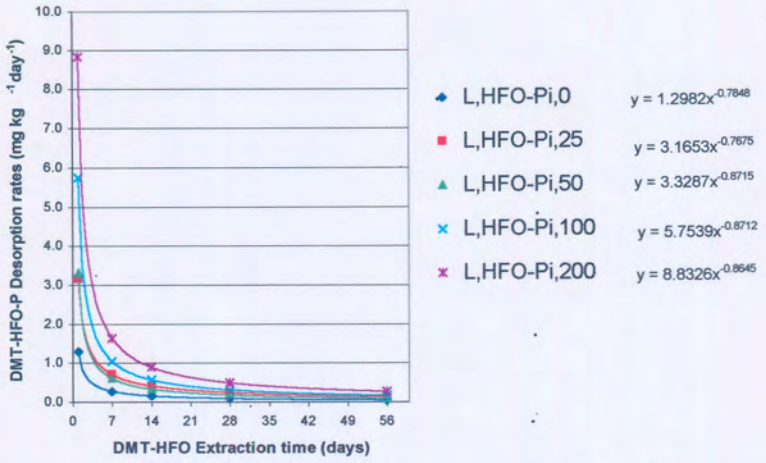

Fig. 2.2a. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

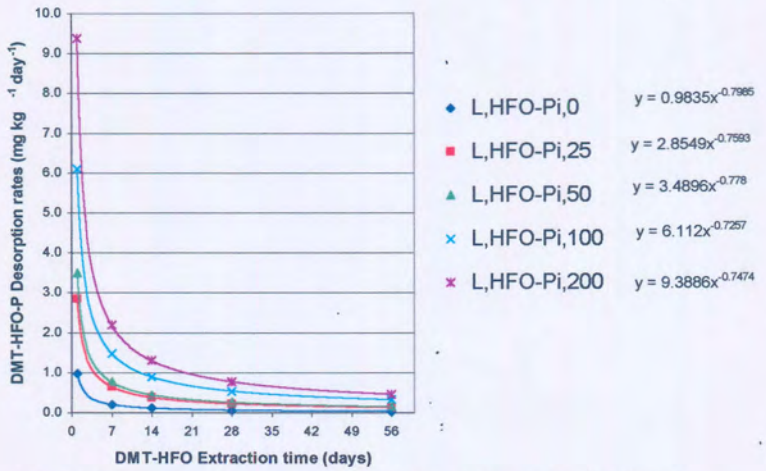

Fig. 2.2b. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

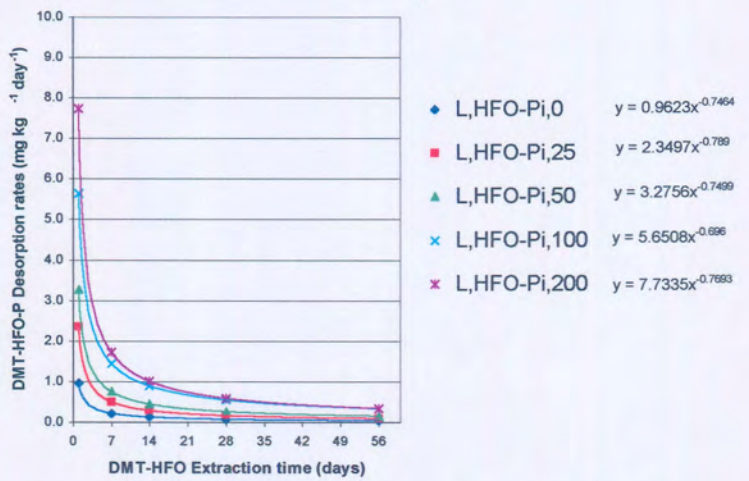

Fig. 2.2c. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

Similarly the contributions of DMT-HFO extracts to the total P pool also reduced from 12.62 and 30.61 % (1 day) to 6.48 and 23.29 % after 240 days of incubation. But, these values are two to three times higher than those from the Rustenburg soil. The percentages increased with the successive DMT-HFO extractions and the added P levels, but were markedly reduced with increases in the days of incubation (Tables 4-18).

In another related experiment, Indiati (1998) working with three Italian soils carried out ten successive extractions over a ten-week period and found that during the first extraction, the soils released between 19.8-24.2 mg kg^{-1} and the cumulative P released after the ten successive extractions was between 79.4-153.5 mg kg^{-1}. These represented 4-13% and 29-46% of the added P removed from the soils at the first, and cumulatively, after the tenth extractions respectively. His results were consistent with findings from a green house experiment by Novais and Kamprath (1978) carried out on heavily P fertilized soils to determine the capacity of the soil to supply P after nine successive crops on extractable soil P.

Thus, Indiati (1998) observed that soil extractable (labile) P alone, may not provide adequate information on P status of the soil especially in terms of the long-term capacity of the soil to supply P for plant growth and concluded that the successive soil P extraction procedure carried out using Fe oxide-impregnated paper strips (or in this case DMT-HFO) provided a convenient laboratory method for characterization of P desorptions from soils by simulating plant P uptake, and therefore for identifying the residual effectiveness of added P fertilizer.

Further, it has been shown that the percent P recoveries of a soil are dependent on the conditions under which the soil and P are allowed to react. In their study, Raven and Hossner (1994) reported that a relatively high proportion of the added P (67-85%) was recovered after 31 days of incubation. But, Sharpley and Smith (1985) had reported that 78 US soils treated with 0-120 mg P kg^{-1}, incubated at field capacity for six months, and subjected to three wetting and drying cycles, only 7-74% of the added P was extracted by the bicarbonate saturated anion-exchange resin (roughly

equivalent to DMT-HFO-P_i). The high percent recoveries in Raven and Hossner (1994) study were probably due to the relatively short incubation time (31 days) and the absence of wetting and drying cycles.

In this study the cumulative P extraction curves had not levelled off for either soil, indicating that P desorption could continue for longer periods than the 56 days used in this experiment (Figs. 1a-c, 1.2a-c and 2.1a-c, 2.2a-c). However, Mckean and Warren (1996), using successive resin extractions (equivalent to DMT-HFO) found that after eight extractions, most of desorption curves were reaching a plateau, and very little additional P could be extracted. Their results showed that in some soils, the cumulative P extraction curves reached plateaux where no more P could be recovered, while others continued to release P slowly. This implied that in some of these soils, there was continued release of adsorbed P. This property could be relevant for the crops in the field with respect to the residual effect of added fertilizer P. Thus, a knowledge of the type of cumulative P extraction curve of the soil, i.e. whether it reaches a plateau or whether it continues to release P is important in the economical management of fertilizer applications.

In practical terms this P release rate can be evaluated when it is considered that a cotton crop removes approximately 15 kg P ha^{-1} to produce 1 000 kg ha^{-1} seed cotton yields (maximum yield 4 500 kg ha^{-1}), while flue cured tobacco (where 70 % of total mass is removed as leaves and 30 % as stalks that are usually ploughed back) requires also up to 15 kg P ha^{-1} for a 1 000 kg ha^{-1} yield (maximum yield 4 000 kg ha^{-1}) (Reuter, 1986). Both these requirements can be met by the two soils, since both soils are able to release between 0.4-0.5 mg kg^{-1} day^{-1} after 56 days of successive extractions. This represents a P release rate of approximately between 1.7 and 2.2 kg P ha^{-1} day^{-1} (soil depth = 30 cm; bulk density = 1 500 kg m^3).

These results therefore show that although Rustenburg soil is considered to be a high P fixing soil the P release rates are still high enough to meet the cotton and tobacco crops requirements. The problems rather could be attributed to the root systems of the crops grown, since if the roots do not develop extensively enough to be able to exploit the soil volume well in order to extract P efficiently, plants may experience P deficiencies.

Further, at this P release rate per ha^{-1} (30 cm) day^{-1} of 1.7-2.2 kg P ha^{-1} day^{-1} after 56 days DMT-HFO extractions may seem low, but it should also be realised that in practice in the field the crop requirements at the beginning of the growing season is small and the extraction rates (P uptake) will thus be smaller. It means that if less P had been extracted during the first 14 days of extractions and that the desorption rates would not have decreased so much within the first 14 days but over a longer period. This assumption is made because over the 240 days of incubation there were less P extracted over the 56 days but the changes in desorption rates were quite similar. The total amount of P extracted would also indicate that both soils were able to supply enough P over the growing seasons for both cotton and tobacco crops.

It should be observed here that routine soil extractable (labile) P alone (e.g. Bray 1 or 2), does not provide adequate information on P status of the soil especially in terms of the long-term capacity of the soil to supply P for plant growth. Therefore, it should be noted that the successive soil P extraction procedure carried out using DMT-HFO provide a convenient laboratory method for characterizing P desorptions from soils by simulating plant P uptake. It is also useful for identifying the residual effectiveness of added fertilizer P. However, although the method is ideal for evaluation of plant available P over a longer period of time, it would not be practical to use as a routine soil analysis as it is expensive and time consuming.

It is foreseeable that by using this method the P releasing properties of a soil could be determined that would probably not fluctuate much. A P desorption model could then be developed using this method. With such a model it could be possible to determine how much extractable P in a particular soil should be available at the beginning of a

growing season and have a high enough P releasing rate to meet plants requirement even up to the end of the growing season.

2b: The effects of the added P, incubation time, and successive DMT-HFO extractions on the plant–available (labile) P pool (0.5M $NaHCO_3$-P_i and P_o)

2b: (i). Rustenburg soil

0.5M $NaHCO_3$-P_i extracts:

The changes in the 0.5M $NaHCO_3$ extractable P after the successive DMT-HFO extractions as shown in Tables 1a-3a, and Figures 3, 3.1 and 3.2 are highly significant at 1 % level (Appendices II No. 2).

For the Rustenburg soil, after one day of DMT-HFO extraction, the amounts of the –HCO_3-P_i extracted reduced from 7.0 and 69.8 (1 day) to 2.8 and 18.8 mg kg^{-1} after 240 days of incubation (between 0 and 200 mg kg^{-1} added P). After 56 days of the successive DMT-HFO extractions the values drastically reduced from 2.77 and 27.33 (1 day) to 1.87 and 9.13 mg kg^{-1} after 240 days of incubation between 0 and 200 mg kg^{-1} added P.

In terms of the percentage recoveries of the added P, the –HCO_3-P_i after 1 day of DMT-HFO extraction, the values remained unchanged at 31 % (1 day) but reduced to 9.88 and 8.00 % after 240 days of incubation between the lowest and highest applied P levels. While the percent P recovered after 56 days of successive DMT-HFO extractions decreased from 3.52 and 12.28 (1 day) to 1.72 and 3.63 % after 240 days of incubation between 25 and 200 mg kg^{-1} added P respectively.

Table 4a. The effects of added P on the changes and distribution of P into different P pools after 1 day of DMT-HFO extractions and 1 day of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	3.22	7.00	11.50	30.13	12.97	8.43	48.33	7.00	56.67	31.47	153.78	185.25
	% of Total P	1.74	3.78	6.21	16.26	7.00	4.55	26.09	3.78	30.59	16.99	83.01	
25	Extracted P	7.50	14.77	11.60	32.80	13.17	10.73	50.60	7.30	59.92	32.07	176.32	208.39
	% of Total P	3.60	7.09	5.57	15.74	6.32	5.15	24.28	3.50	28.75	15.39	84.61	
50	Extracted P	17.92	20.80	12.27	41.70	14.03	13.53	51.20	8.20	61.72	34.50	206.87	241.37
	% of Total P	7.42	8.62	5.08	17.28	5.81	5.61	21.21	3.40	25.57	14.29	85.71	
100	Extracted P	26.57	33.40	12.50	56.40	14.80	15.50	52.00	8.67	67.83	35.97	251.70	287.67
	% of Total P	9.24	11.61	4.35	19.61	5.14	5.39	18.08	3.01	23.58	12.50	87.50	
200	Extracted P	46.18	69.80	13.53	90.47	15.30	20.62	54.67	9.70	69.83	38.53	351.57	390.10
	% of Total P	11.84	17.89	3.47	23.19	3.92	5.29	14.01	2.49	17.90	9.88	90.12	
Average Extracted P		20.28	29.15	12.28	50.30	14.05	13.76	51.36	8.17	63.19	34.51	228.05	262.56
Average % of Total P		6.77	9.80	4.93	18.42	5.64	5.20	20.73	3.24	25.28	13.81	86.19	

Table 4b. The effects of added P on the changes and distribution of P into different P pools after 1day of DMT-HFO extractions and 1 day of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	6.30	12.27	7.07	25.33	9.20	6.13	31.10	5.07	45.75	21.34	126.88	148.22
	% of Total P	4.25	8.28	4.77	17.09	6.21	4.14	20.98	3.42	30.87	14.40	85.60	
25	Extracted P	13.93	18.87	8.00	28.13	11.93	7.90	32.53	5.97	46.92	25.90	148.28	174.18
	% of Total P	8.00	10.83	4.59	16.15	6.85	4.54	18.68	3.43	26.94	14.87	85.13	
50	Extracted P	27.38	25.00	8.47	31.77	12.43	8.77	33.67	6.17	48.17	27.07	174.76	201.83
	% of Total P	13.57	12.39	4.20	15.74	6.16	4.35	16.68	3.06	23.87	13.41	86.59	
100	Extracted P	46.68	42.73	9.93	37.20	13.53	12.80	35.53	6.50	50.67	29.96	225.61	255.57
	% of Total P	18.27	16.72	3.89	14.56	5.29	5.01	13.90	2.54	19.83	11.72	88.28	
200	Extracted P	67.22	78.00	10.80	65.93	15.13	14.07	40.53	7.47	53.87	33.40	319.62	353.02
	% of Total P	19.04	22.10	3.06	18.68	4.29	3.99	11.48	2.12	15.26	9.46	90.54	
Average Extracted P		32.30	35.37	8.85	37.67	12.44	9.93	34.67	6.24	49.08	27.53	199.03	226.56
Average % of Total P		12.62	14.06	4.10	16.44	5.76	4.40	16.34	2.91	23.35	12.77	87.23	

Table 5a. The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 1 day of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	6.24	6.50	3.50	22.90	9.63	5.95	41.27	5.47	39.33	18.60	122.19	140.79
	% of Total P	4.43	4.62	2.49	16.27	6.84	4.23	29.31	3.89	27.94	13.21	86.79	
25	Extracted P	11.93	11.47	4.70	24.43	10.90	8.00	43.67	5.67	44.50	21.27	144.00	165.27
	% of Total P	7.22	6.94	2.84	14.78	6.60	4.84	26.42	3.43	26.93	12.87	87.13	
50	Extracted P	21.00	18.83	5.50	27.00	11.67	10.33	45.53	7.13	47.67	24.30	170.36	194.66
	% of Total P	10.79	9.67	2.83	13.87	6.00	5.31	23.39	3.66	24.49	12.48	87.52	
100	Extracted P	35.72	27.13	7.77	42.23	12.90	13.80	48.53	7.47	51.75	28.14	219.16	247.30
	% of Total P	14.44	10.97	3.14	17.08	5.22	5.58	19.62	3.02	20.93	11.38	88.62	
200	Extracted P	61.50	48.27	9.37	65.80	14.13	17.25	54.20	7.90	59.67	31.40	306.69	338.09
	% of Total P	18.19	14.28	2.77	19.46	4.18	5.10	16.03	2.34	17.65	9.29	90.71	
Average Extracted P		27.28	22.44	6.17	36.47	11.85	11.07	46.64	6.73	48.58	24.74	192.48	217.22
Average % of Total P		11.01	9.30	2.81	16.29	5.77	5.01	22.96	3.27	23.58	11.85	88.15	

Table 5b. The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 1 day of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	8.42	12.00	4.63	20.83	7.10	4.87	29.27	3.93	34.33	15.66	109.72	125.38
	% of Total P	6.72	9.57	3.69	16.61	5.66	3.88	23.35	3.13	27.38	12.49	87.51	
25	Extracted P	20.50	14.43	5.70	24.13	9.47	6.80	30.33	4.33	35.67	19.50	131.86	151.36
	% of Total P	13.54	9.53	3.77	15.94	6.26	4.49	20.04	2.86	23.57	12.88	87.12	
50	Extracted P	30.17	22.77	4.90	28.30	10.30	6.93	32.60	4.73	36.33	19.93	157.10	177.03
	% of Total P	17.04	12.86	2.77	15.99	5.82	3.91	18.41	2.67	20.52	11.26	88.74	
100	Extracted P	53.67	33.13	7.87	32.90	11.30	9.20	34.60	5.35	39.67	24.52	203.17	227.69
	% of Total P	23.57	14.55	3.46	14.45	4.96	4.04	15.20	2.35	17.42	10.77	89.23	
200	Extracted P	80.17	58.77	8.00	62.70	13.83	12.33	39.60	6.50	44.00	28.33	297.57	325.90
	% of Total P	24.60	18.03	2.45	19.24	4.24	3.78	12.15	1.99	13.50	8.69	91.31	
Average Extracted P		38.59	28.22	6.22	33.77	10.40	8.03	33.28	4.97	38.00	21.59	179.88	201.47
Average % of Total P		17.09	12.91	3.23	16.45	5.39	4.02	17.83	2.60	20.48	11.22	88.78	

Table 6a. The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 1 day of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	7.77	5.30	1.97	18.58	8.55	5.20	40.53	4.50	36.03	15.02	113.41	128.43
	% of Total P	6.05	4.13	1.53	14.47	6.66	4.05	31.56	3.50	28.05	11.70	88.30	
25	Extracted P	13.97	9.83	4.40	21.33	9.33	7.75	44.60	5.00	38.17	18.73	135.65	154.38
	% of Total P	9.05	6.37	2.85	13.82	6.04	5.02	28.89	3.24	24.72	12.13	87.87	
50	Extracted P	26.73	12.63	4.20	23.33	10.00	9.40	44.53	6.00	43.40	20.20	160.02	180.22
	% of Total P	14.83	7.01	2.33	12.95	5.55	5.22	24.71	3.33	24.08	11.21	88.79	
100	Extracted P	45.18	22.17	6.50	34.83	11.50	12.80	46.80	6.00	50.77	24.00	212.55	236.55
	% of Total P	19.10	9.37	2.75	14.72	4.86	5.41	19.78	2.54	21.46	10.15	89.85	
200	Extracted P	72.85	45.17	7.40	58.00	13.17	14.70	53.53	7.60	55.93	28.17	300.18	328.35
	% of Total P	22.19	13.76	2.25	17.66	4.01	4.48	16.30	2.31	17.03	8.58	91.42	
Average Extracted P		33.30	19.02	4.89	31.21	10.51	9.97	46.00	5.82	44.86	21.22	184.36	205.59
Average % of Total P		14.24	8.13	2.34	14.72	5.42	4.83	24.25	2.98	23.07	10.75	89.25	

Table 6b. The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 1 day of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	10.50	9.07	3.13	19.45	6.35	4.72	27.87	2.80	32.87	12.28	104.48	116.76
	% of Total P	8.99	7.77	2.68	16.66	5.44	4.04	23.87	2.40	28.15	10.52	89.48	
25	Extracted P	24.03	12.00	4.27	22.07	8.97	6.47	28.80	3.07	33.63	16.31	127.00	143.31
	% of Total P	16.77	8.37	2.98	15.40	6.26	4.51	20.10	2.14	23.47	11.38	88.62	
50	Extracted P	35.58	16.50	4.50	25.83	9.57	6.67	30.53	3.90	34.87	17.97	149.98	167.95
	% of Total P	21.18	9.82	2.68	15.38	5.70	3.97	18.18	2.32	20.76	10.70	89.30	
100	Extracted P	60.05	28.30	6.57	29.50	10.80	8.50	33.60	4.80	37.60	22.17	197.55	219.72
	% of Total P	27.33	12.88	2.99	13.43	4.92	3.87	15.29	2.18	17.11	10.09	89.91	
200	Extracted P	92.80	50.47	7.20	56.07	11.47	11.00	37.93	6.00	43.90	24.67	292.17	316.84
	% of Total P	29.29	15.93	2.27	17.70	3.62	3.47	11.97	1.89	13.86	7.79	92.21	
Average Extracted P		44.59	23.27	5.13	30.58	9.43	7.47	31.75	4.11	36.57	18.68	174.24	192.92
Average % of Total P		20.71	10.96	2.72	15.71	5.19	3.97	17.88	2.19	20.67	10.09	89.91	

Table 7a. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 1 day of incubation for Rustenburg soil.

Added P ($mg\ kg^{-1}$)	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	10.70	4.30	1.37	14.77	7.00	5.10	38.60	4.00	30.42	12.37	103.89	116.26
	% of Total P	9.20	3.70	1.18	12.70	6.02	4.39	33.20	3.44	26.17	10.64	89.36	
25	Extracted P	24.47	5.10	3.23	18.30	8.00	7.07	40.20	4.40	31.83	15.63	126.97	142.60
	% of Total P	17.16	3.58	2.27	12.83	5.61	4.96	28.19	3.09	22.32	10.96	89.04	
50	Extracted P	31.77	11.60	3.13	21.77	9.53	9.20	41.33	5.50	37.67	18.16	153.34	171.50
	% of Total P	18.52	6.76	1.83	12.69	5.56	5.36	24.10	3.21	21.97	10.59	89.41	
100	Extracted P	52.68	16.23	5.17	28.33	10.00	11.50	43.60	6.07	43.25	21.24	195.59	216.83
	% of Total P	24.30	7.49	2.38	13.07	4.61	5.30	20.11	2.80	19.95	9.80	90.20	
200	Extracted P	81.23	38.00	6.40	48.30	12.53	14.27	52.67	6.50	53.83	25.43	288.30	313.73
	% of Total P	25.89	12.11	2.04	15.40	3.99	4.55	16.79	2.07	17.16	8.11	91.89	
Average Extracted P		40.17	15.05	3.86	26.29	9.41	9.43	43.28	5.29	39.40	18.57	173.62	192.18
Average % of Total P		19.02	6.73	1.94	13.34	5.16	4.91	24.48	2.92	21.51	10.02	89.98	

Table 7b. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 1 day of incubation for Loskop soil.

Added P ($mg\ kg^{-1}$)	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	12.75	7.47	2.87	15.93	5.00	4.50	26.20	2.40	25.75	10.27	92.60	102.87
	% of Total P	12.39	7.26	2.79	15.49	4.86	4.37	25.47	2.33	25.03	9.98	90.02	
25	Extracted P	32.25	8.57	2.97	18.13	6.53	5.32	27.33	2.67	25.95	12.17	117.55	129.72
	% of Total P	24.86	6.61	2.29	13.98	5.03	4.10	21.07	2.06	20.00	9.38	90.62	
50	Extracted P	40.35	13.27	3.07	22.67	8.27	6.00	28.93	3.50	28.42	14.84	139.64	154.48
	% of Total P	26.12	8.59	1.99	14.68	5.35	3.88	18.73	2.27	18.40	9.61	90.39	
100	Extracted P	71.05	20.50	5.50	25.77	9.50	7.80	31.27	4.20	33.58	19.20	189.97	209.17
	% of Total P	33.97	9.80	2.63	12.32	4.54	3.73	14.95	2.01	16.05	9.18	90.82	
200	Extracted P	102.50	42.53	6.53	49.80	10.80	9.67	36.27	5.00	40.60	22.33	281.37	303.70
	% of Total P	33.75	14.00	2.15	16.40	3.56	3.18	11.94	1.65	13.37	7.35	92.65	
Average Extracted P		51.78	18.47	4.19	26.46	8.02	6.66	30.00	3.55	30.86	15.76	164.23	179.99
Average % of Total P		26.22	9.25	2.37	14.57	4.67	3.85	18.43	2.06	18.57	9.10	90.90	

Table 8a. The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 1 day of incubation for Rustenburg soil.

Added P ($mg\ kg^{-1}$)	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	12.18	2.77	1.13	10.77	6.10	5.00	35.77	3.27	26.08	10.50	92.57	103.07
	% of Total P	11.82	2.69	1.10	10.45	5.92	4.85	34.70	3.17	25.30	10.19	89.81	
25	Extracted P	28.50	3.65	2.22	11.80	7.53	6.60	37.07	3.47	28.25	13.22	115.87	129.09
	% of Total P	22.08	2.83	1.72	9.14	5.83	5.11	28.72	2.69	21.88	10.24	89.76	
50	Extracted P	38.75	8.80	2.40	14.67	9.00	8.57	38.33	4.83	31.20	16.23	140.32	156.55
	% of Total P	24.75	5.62	1.53	9.37	5.75	5.47	24.48	3.09	19.93	10.37	89.63	
100	Extracted P	65.00	12.00	3.87	22.77	9.50	10.87	42.47	5.28	36.50	18.65	189.61	208.26
	% of Total P	31.21	5.76	1.86	10.93	4.56	5.22	20.39	2.54	17.53	8.96	91.04	
200	Extracted P	96.77	27.33	5.27	42.27	11.83	13.23	49.87	6.13	46.90	23.23	276.37	299.60
	% of Total P	32.30	9.12	1.76	14.11	3.95	4.42	16.65	2.05	15.65	7.75	92.25	
Average Extracted P		48.24	10.91	2.98	20.46	8.79	8.85	40.70	4.60	33.79	16.37	162.95	179.31
Average % of Total P		24.43	5.20	1.59	10.80	5.20	5.01	24.99	2.71	20.06	9.50	90.50	

Table 8b. The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 1 day of incubation for Loskop soil.

Added P ($mg\ kg^{-1}$)	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	14.70	5.80	1.53	13.40	4.77	4.30	25.87	2.23	23.78	8.53	87.85	96.38
	% of Total P	15.25	6.02	1.59	13.90	4.95	4.46	26.84	2.31	24.67	8.85	91.15	
25	Extracted P	33.97	7.57	1.77	14.72	6.62	4.93	26.27	2.40	24.50	10.79	111.96	122.75
	% of Total P	27.67	6.17	1.44	11.99	5.39	4.02	21.40	1.96	19.96	8.79	91.21	
50	Extracted P	45.65	10.17	2.50	20.82	7.42	5.42	27.93	3.20	25.68	13.12	135.67	148.79
	% of Total P	30.68	6.84	1.68	13.99	4.99	3.64	18.77	2.15	17.26	8.82	91.18	
100	Extracted P	77.53	15.33	4.00	22.00	8.00	7.00	30.60	3.87	29.58	15.87	182.04	197.91
	% of Total P	39.17	7.75	2.02	11.12	4.04	3.54	15.46	1.96	14.95	8.02	91.98	
200	Extracted P	115.87	31.83	5.00	39.45	10.02	9.10	34.77	4.57	37.22	19.59	268.24	287.83
	% of Total P	40.26	11.06	1.74	13.71	3.48	3.16	12.08	1.59	12.93	6.81	93.19	
Average Extracted P		57.54	14.14	2.96	22.08	7.37	6.15	29.09	3.25	28.15	13.58	157.15	170.73
Average % of Total P		30.61	7.56	1.69	12.94	4.57	3.76	18.91	1.99	17.95	8.26	91.74	

Table 9a. The effects of added P on the changes and distribution of P into different P pools after 1 day of DMT-HFO extractions and 120 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	3.25	3.97	9.03	44.83	12.37	7.72	51.27	7.07	58.42	28.47	169.46	197.93
	% of Total P	1.64	2.01	4.56	22.65	6.25	3.90	25.90	3.57	29.52	14.38	85.62	
25	Extracted P	3.52	6.22	10.45	57.83	13.63	11.92	52.53	7.60	60.92	31.68	192.94	224.62
	% of Total P	1.57	2.77	4.65	25.75	6.07	5.31	23.39	3.38	27.12	14.10	85.90	
50	Extracted P	6.97	9.50	12.33	62.10	14.23	13.07	55.40	8.53	68.67	35.09	215.71	250.80
	% of Total P	2.78	3.79	4.92	24.76	5.67	5.21	22.09	3.40	27.38	13.99	86.01	
100	Extracted P	11.38	14.58	14.92	74.17	18.60	16.87	61.17	10.10	79.08	43.62	257.25	300.87
	% of Total P	3.78	4.85	4.96	24.65	6.18	5.61	20.33	3.36	26.28	14.50	85.50	
200	Extracted P	21.63	23.02	17.25	100.67	25.20	28.93	76.60	12.37	92.67	54.82	343.52	398.34
	% of Total P	5.43	5.78	4.33	25.27	6.33	7.26	19.23	3.11	23.26	13.76	86.24	
Average Extracted P		9.35	11.46	12.80	67.92	16.81	15.70	59.39	9.13	71.95	38.74	235.78	274.51
Average % of Total P		3.04	3.84	4.68	24.62	6.10	5.46	22.19	3.36	26.71	14.15	85.85	

Table 9b. The effects of added P on the changes and distribution of P into different P pools after 1 day of DMT-HFO extractions and 120 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	5.22	11.27	6.93	29.13	8.13	6.40	32.60	5.40	47.00	20.46	131.62	152.08
	% of Total P	3.43	7.41	4.56	19.15	5.35	4.21	21.44	3.55	30.90	13.45	86.55	
25	Extracted P	12.63	13.57	11.17	33.27	10.20	9.47	34.67	6.27	49.00	27.64	152.61	180.25
	% of Total P	7.01	7.53	6.20	18.46	5.66	5.25	19.23	3.48	27.18	15.33	84.67	
50	Extracted P	16.72	20.87	11.67	36.93	11.40	10.00	36.87	7.63	51.33	30.70	172.72	203.42
	% of Total P	8.22	10.26	5.74	18.15	5.60	4.92	18.13	3.75	25.23	15.09	84.91	
100	Extracted P	24.27	35.47	13.20	47.00	14.27	14.80	40.13	10.57	55.67	38.04	217.34	255.38
	% of Total P	9.50	13.89	5.17	18.40	5.59	5.80	15.71	4.14	21.80	14.90	85.10	
200	Extracted P	39.63	56.33	13.65	78.60	17.07	18.93	50.27	13.48	64.83	44.20	308.59	352.79
	% of Total P	11.23	15.97	3.87	22.28	4.84	5.37	14.25	3.82	18.38	12.53	87.47	
Average Extracted P		19.69	27.50	11.32	44.99	12.21	11.92	38.91	8.67	53.57	32.21	196.58	228.78
Average % of Total P		7.88	11.01	5.11	19.29	5.41	5.11	17.75	3.75	24.70	14.26	85.74	

Table 10a.The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 120 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	5.05	3.27	7.33	35.87	10.28	6.13	43.33	4.73	45.67	22.34	139.32	161.66
	% of Total P	3.12	2.02	4.53	22.19	6.36	3.79	26.80	2.93	28.25	13.82	86.18	
25	Extracted P	7.17	4.47	8.35	43.27	12.37	9.43	46.27	6.03	49.75	26.75	160.36	187.11
	% of Total P	3.83	2.39	4.46	23.13	6.61	5.04	24.73	3.22	26.59	14.30	85.70	
50	Extracted P	12.83	7.60	9.97	47.60	13.10	12.50	49.00	7.23	54.58	30.30	184.11	214.41
	% of Total P	5.98	3.54	4.65	22.20	6.11	5.83	22.85	3.37	25.46	14.13	85.87	
100	Extracted P	21.52	10.93	11.57	59.05	15.88	15.00	54.67	8.27	67.90	35.72	229.07	264.79
	% of Total P	8.13	4.13	4.37	22.30	6.00	5.66	20.65	3.12	25.64	13.49	86.51	
200	Extracted P	36.38	19.77	14.03	75.87	20.33	24.50	73.87	9.83	85.80	44.19	316.19	360.38
	% of Total P	10.09	5.49	3.89	21.05	5.64	6.80	20.50	2.73	23.81	12.26	87.74	
Average Extracted P		16.59	9.21	10.25	52.33	14.39	13.51	53.43	7.22	60.74	31.86	205.81	237.67
Average % of Total P		6.23	3.51	4.38	22.17	6.14	5.42	23.11	3.07	25.95	13.60	86.40	

Table 10b. The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 120 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	6.72	10.47	4.03	25.13	6.07	5.77	30.00	4.33	35.17	14.43	113.26	127.69
	% of Total P	5.26	8.20	3.16	19.68	4.75	4.52	23.49	3.39	27.54	11.30	88.70	
25	Extracted P	16.77	11.00	6.40	27.67	8.20	8.27	31.33	5.50	38.80	20.10	133.84	153.94
	% of Total P	10.89	7.15	4.16	17.97	5.33	5.37	20.35	3.57	25.20	13.06	86.94	
50	Extracted P	22.53	15.33	6.93	32.27	9.07	9.87	34.47	7.20	41.50	23.20	155.97	179.17
	% of Total P	12.57	8.56	3.87	18.01	5.06	5.51	19.24	4.02	23.16	12.95	87.05	
100	Extracted P	32.87	24.77	8.77	40.63	12.17	12.73	38.33	9.00	47.50	29.94	196.83	226.77
	% of Total P	14.49	10.92	3.87	17.92	5.37	5.61	16.90	3.97	20.95	13.20	86.80	
200	Extracted P	54.37	46.10	10.90	67.43	14.83	14.27	49.67	11.00	57.00	36.73	288.84	325.57
	% of Total P	16.70	14.16	3.35	20.71	4.56	4.38	15.26	3.38	17.51	11.28	88.72	
Average Extracted P		26.65	21.53	7.41	38.63	10.07	10.18	36.76	7.41	43.99	24.88	177.75	202.63
Average % of Total P		11.99	9.80	3.68	18.86	5.01	5.08	19.05	3.67	22.87	12.36	87.64	

Table 11a. The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 120 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	6.33	3.07	6.50	30.83	9.37	6.00	41.77	4.55	40.75	20.42	128.75	149.17
	% of Total P	4.24	2.06	4.36	20.67	6.28	4.02	28.00	3.05	27.32	13.69	86.31	
25	Extracted P	12.28	4.10	6.90	38.10	11.07	8.80	43.20	5.17	45.13	23.14	151.61	174.75
	% of Total P	7.03	2.35	3.95	21.80	6.33	5.04	24.72	2.96	25.83	13.24	86.76	
50	Extracted P	21.12	6.10	8.47	43.90	12.30	10.43	45.93	6.27	49.77	27.04	177.25	204.29
	% of Total P	10.34	2.99	4.15	21.49	6.02	5.11	22.48	3.07	24.36	13.24	86.76	
100	Extracted P	32.53	10.30	9.77	50.90	13.30	14.43	53.40	7.27	61.45	30.34	223.01	253.35
	% of Total P	12.84	4.07	3.86	20.09	5.25	5.70	21.08	2.87	24.25	11.98	88.02	
200	Extracted P	45.30	14.97	12.47	69.10	18.23	22.67	71.20	9.13	77.50	39.83	300.74	340.57
	% of Total P	13.30	4.40	3.66	20.29	5.35	6.66	20.91	2.68	22.76	11.70	88.30	
Average Extracted P		23.51	7.71	8.82	46.57	12.85	12.47	51.10	6.48	54.92	28.15	196.27	224.43
Average % of Total P		9.55	3.17	3.99	20.87	5.85	5.30	23.44	2.93	24.90	12.77	87.23	

Table 11b.The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 120 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	7.72	7.80	3.53	21.43	4.97	5.55	29.67	4.00	30.75	12.50	102.92	115.42
	% of Total P	6.69	6.76	3.06	18.57	4.31	4.81	25.71	3.47	26.64	10.83	89.17	
25	Extracted P	22.22	9.53	5.58	23.60	6.13	7.10	30.00	5.08	33.00	16.79	125.45	142.24
	% of Total P	15.62	6.70	3.92	16.59	4.31	4.99	21.09	3.57	23.20	11.80	88.20	
50	Extracted P	26.52	13.00	5.33	29.97	8.50	8.93	32.27	6.80	38.25	20.63	148.94	169.57
	% of Total P	15.64	7.67	3.14	17.67	5.01	5.27	19.03	4.01	22.56	12.17	87.83	
100	Extracted P	43.42	20.13	6.53	38.43	10.83	10.53	37.67	8.00	40.33	25.36	190.51	215.87
	% of Total P	20.11	9.33	3.02	17.80	5.02	4.88	17.45	3.71	18.68	11.75	88.25	
200	Extracted P	70.17	40.93	8.33	59.77	12.80	12.20	48.67	9.67	53.00	30.80	284.74	315.54
	% of Total P	22.24	12.97	2.64	18.94	4.06	3.87	15.42	3.06	16.80	9.76	90.24	
Average Extracted P		34.01	18.28	5.86	34.64	8.65	8.86	35.66	6.71	39.07	21.22	170.51	191.73
Average % of Total P		16.06	8.68	3.16	17.92	4.54	4.76	19.74	3.56	21.58	11.26	88.74	

Table 12a. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 120 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	7.15	2.93	5.00	25.47	8.07	5.53	38.93	3.63	33.88	16.70	113.89	130.59
	% of Total P	5.48	2.24	3.83	19.50	6.18	4.23	29.81	2.78	25.94	12.79	87.21	
25	Extracted P	17.33	3.20	5.97	28.80	9.93	7.92	41.53	4.23	38.02	20.13	136.80	156.93
	% of Total P	11.04	2.04	3.80	18.35	6.33	5.05	26.46	2.70	24.23	12.83	87.17	
50	Extracted P	25.78	5.20	7.63	34.73	11.40	9.23	42.87	6.03	44.30	25.06	162.11	187.17
	% of Total P	13.77	2.78	4.08	18.56	6.09	4.93	22.90	3.22	23.67	13.39	86.61	
100	Extracted P	42.25	8.93	8.47	43.93	13.00	12.53	47.00	6.33	50.98	27.80	205.62	233.42
	% of Total P	18.10	3.83	3.63	18.82	5.57	5.37	20.14	2.71	21.84	11.91	88.09	
200	Extracted P	60.02	12.20	10.13	64.97	16.10	20.03	68.20	8.00	70.23	34.23	295.65	329.88
	% of Total P	18.19	3.70	3.07	19.70	4.88	6.07	20.67	2.43	21.29	10.38	89.62	
Average Extracted P		30.51	6.49	7.44	39.58	11.70	11.05	47.71	5.64	47.48	24.78	182.81	207.60
Average % of Total P		13.32	2.92	3.68	18.99	5.81	5.13	24.00	2.77	23.39	12.26	87.74	

Table 12b. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 120 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	9.30	5.90	2.00	19.27	4.33	5.33	27.20	3.67	28.67	10.00	95.67	105.67
	% of Total P	8.80	5.58	1.89	18.24	4.10	5.04	25.74	3.47	27.13	9.46	90.54	
25	Extracted P	26.88	7.28	3.00	21.10	5.37	6.13	29.00	4.50	30.08	12.87	120.47	133.34
	% of Total P	20.16	5.46	2.25	15.82	4.03	4.60	21.75	3.37	22.56	9.65	90.35	
50	Extracted P	32.40	10.97	4.03	26.93	6.53	7.60	31.53	5.60	31.92	16.16	141.35	157.51
	% of Total P	20.57	6.96	2.56	17.10	4.15	4.83	20.02	3.56	20.27	10.26	89.74	
100	Extracted P	58.53	15.07	4.80	33.67	9.13	9.47	35.93	6.93	34.42	20.86	187.09	207.95
	% of Total P	28.15	7.25	2.31	16.19	4.39	4.55	17.28	3.33	16.55	10.03	89.97	
200	Extracted P	88.43	32.70	5.97	51.07	11.60	11.60	46.33	8.00	47.87	25.57	278.00	303.57
	% of Total P	29.13	10.77	1.97	16.82	3.82	3.82	15.26	2.64	15.77	8.42	91.58	
Average Extracted P		43.11	14.38	3.96	30.41	7.39	8.03	34.00	5.74	34.59	17.09	164.52	181.61
Average % of Total P		21.36	7.21	2.20	16.83	4.10	4.57	20.01	3.27	20.46	9.57	90.43	

Table 13a. The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 120 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	10.42	2.60	4.28	23.23	6.83	4.97	35.83	2.57	31.33	13.68	108.38	122.06
	% of Total P	8.54	2.13	3.51	19.03	5.60	4.07	29.35	2.11	25.67	11.21	88.79	
25	Extracted P	23.52	2.93	4.80	25.43	8.50	6.92	37.33	3.53	33.92	16.83	130.05	146.88
	% of Total P	16.01	1.99	3.27	17.31	5.79	4.71	25.42	2.40	23.09	11.46	88.54	
50	Extracted P	34.47	5.33	6.50	31.03	10.23	8.80	40.53	5.07	36.52	21.80	156.68	178.48
	% of Total P	19.31	2.99	3.64	17.39	5.73	4.93	22.71	2.84	20.46	12.21	87.79	
100	Extracted P	52.83	8.20	7.63	41.83	11.50	11.87	45.87	6.03	45.60	25.16	206.20	231.36
	% of Total P	22.83	3.54	3.30	18.08	4.97	5.13	19.83	2.61	19.71	10.87	89.13	
200	Extracted P	74.73	11.27	8.73	56.40	14.60	18.13	65.93	6.67	66.42	30.00	292.88	322.88
	% of Total P	23.14	3.49	2.70	17.47	4.52	5.62	20.42	2.07	20.57	9.29	90.71	
Average Extracted P		39.19	6.07	6.39	35.58	10.33	10.14	45.10	4.77	42.76	21.49	178.84	200.33
Average % of Total P		17.97	2.83	3.28	17.86	5.32	4.89	23.54	2.40	21.90	11.01	88.99	

Table 13b. The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 120 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	12.20	3.27	1.50	17.57	2.83	4.47	26.13	3.53	24.67	7.86	88.31	96.17
	% of Total P	12.69	3.40	1.56	18.27	2.94	4.65	27.17	3.67	25.65	8.17	91.83	
25	Extracted P	32.87	4.23	2.17	18.75	4.32	5.27	26.60	4.00	25.83	10.49	113.55	124.04
	% of Total P	26.50	3.41	1.75	15.12	3.48	4.25	21.44	3.22	20.82	8.46	91.54	
50	Extracted P	42.03	8.10	3.00	22.57	5.37	7.17	28.33	5.00	28.00	13.37	136.20	149.57
	% of Total P	28.10	5.42	2.01	15.09	3.59	4.79	18.94	3.34	18.72	8.94	91.06	
100	Extracted P	71.67	11.93	3.67	29.25	8.35	8.28	31.93	6.07	30.50	18.09	183.56	201.65
	% of Total P	35.54	5.92	1.82	14.51	4.14	4.11	15.83	3.01	15.13	8.97	91.03	
200	Extracted P	108.50	28.07	4.80	46.20	10.40	10.17	44.60	7.00	42.33	22.20	279.87	302.07
	% of Total P	35.92	9.29	1.59	15.29	3.44	3.37	14.76	2.32	14.01	7.35	92.65	
Average Extracted P		53.45	11.12	3.03	26.87	6.25	7.07	31.52	5.12	30.27	14.40	160.30	174.70
Average % of Total P		27.75	5.49	1.74	15.66	3.52	4.23	19.63	3.11	18.87	8.38	91.62	

Table 14a. The effects of added P on the changes and distribution of P into different P pools after 1 day of DMT-HFO extractions and 240 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	2.85	2.80	6.90	55.17	10.75	9.87	58.70	7.77	60.83	25.42	190.22	215.64
	% of Total P	1.32	1.30	3.20	25.58	4.99	4.58	27.22	3.60	28.21	11.79	88.21	
25	Extracted P	4.30	5.27	9.40	57.98	12.82	14.17	60.00	8.52	68.13	30.74	209.85	240.59
	% of Total P	1.79	2.19	3.91	24.10	5.33	5.89	24.94	3.54	28.32	12.78	87.22	
50	Extracted P	5.27	7.97	11.60	65.67	13.63	18.33	64.40	9.70	76.25	34.93	237.89	272.82
	% of Total P	1.93	2.92	4.25	24.07	5.00	6.72	23.61	3.56	27.95	12.80	87.20	
100	Extracted P	8.17	10.73	12.27	74.00	15.33	22.27	76.30	12.35	91.00	39.95	282.47	322.42
	% of Total P	2.53	3.33	3.81	22.95	4.75	6.91	23.66	3.83	28.22	12.39	87.61	
200	Extracted P	14.62	18.80	14.20	106.17	17.80	27.53	95.80	13.53	116.13	45.53	379.05	424.58
	% of Total P	3.44	4.43	3.34	25.01	4.19	6.48	22.56	3.19	27.35	10.72	89.28	
Average Extracted P		7.04	9.11	10.87	71.80	14.07	18.43	71.04	10.37	82.47	35.31	259.90	295.21
Average % of Total P		2.20	2.83	3.70	24.34	4.85	6.12	24.40	3.54	28.01	12.10	87.90	

Table 14b. The effects of added P on the changes and distribution of P into different P pools after 1 day of DMT-HFO extractions and 240 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	4.13	9.60	6.00	32.93	7.11	6.65	38.00	6.40	47.75	19.51	139.06	158.57
	% of Total P	2.60	6.05	3.78	20.77	4.48	4.19	23.96	4.04	30.11	12.30	87.70	
25	Extracted P	12.13	12.43	8.43	35.10	9.17	9.13	39.27	7.07	52.00	24.67	160.06	184.73
	% of Total P	6.57	6.73	4.56	19.00	4.96	4.94	21.26	3.83	28.15	13.35	86.65	
50	Extracted P	13.43	14.13	10.93	41.10	11.43	12.27	41.93	10.93	56.42	33.29	179.28	212.57
	% of Total P	6.32	6.65	5.14	19.33	5.38	5.77	19.73	5.14	26.54	15.66	84.34	
100	Extracted P	18.73	22.10	11.10	56.30	14.40	16.02	48.47	12.20	61.00	37.70	222.62	260.32
	% of Total P	7.19	8.49	4.26	21.63	5.53	6.15	18.62	4.69	23.43	14.48	85.52	
200	Extracted P	35.20	44.83	12.77	86.53	15.93	19.40	59.27	12.47	75.33	41.17	320.56	361.73
	% of Total P	9.73	12.39	3.53	23.92	4.40	5.36	16.39	3.45	20.82	11.38	88.62	
Average Extracted P		16.72	20.62	9.85	50.39	11.61	12.69	45.39	9.81	58.50	31.27	204.32	235.58
Average % of Total P		6.48	8.06	4.26	20.93	4.95	5.29	19.99	4.23	25.81	13.44	86.56	

Table 15a. The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 240 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	4.50	2.77	5.70	36.50	9.23	7.80	50.00	5.67	50.67	20.60	152.24	172.84
	% of Total P	2.60	1.60	3.30	21.12	5.34	4.51	28.93	3.28	29.32	11.92	88.08	
25	Extracted P	5.70	4.33	7.00	40.35	10.95	11.43	53.90	7.03	58.83	24.98	174.54	199.52
	% of Total P	2.86	2.17	3.51	20.22	5.49	5.73	27.01	3.52	29.49	12.52	87.48	
50	Extracted P	10.92	7.00	8.88	46.75	12.75	14.17	56.07	8.57	64.67	30.20	199.58	229.78
	% of Total P	4.75	3.05	3.86	20.35	5.55	6.17	24.40	3.73	28.14	13.14	86.86	
100	Extracted P	15.00	9.67	10.33	59.50	13.45	16.40	62.93	10.37	78.33	34.15	241.83	275.98
	% of Total P	5.44	3.50	3.74	21.56	4.87	5.94	22.80	3.76	28.38	12.37	87.63	
200	Extracted P	23.13	14.33	11.67	87.97	15.50	20.52	86.10	11.77	103.25	38.94	335.30	374.24
	% of Total P	6.18	3.83	3.12	23.51	4.14	5.48	23.01	3.15	27.59	10.41	89.59	
Average Extracted P		11.85	7.62	8.72	54.21	12.38	14.06	61.80	8.68	71.15	29.77	220.70	250.47
Average % of Total P		4.37	2.83	3.51	21.35	5.08	5.57	25.23	3.49	28.58	12.07	87.93	

Table 15b. The effects of added P on the changes and distribution of P into different P pools after 7 days of DMT-HFO extractions and 240 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	5.82	7.77	4.63	28.87	6.93	6.30	32.67	4.93	41.48	16.49	122.91	139.40
	% of Total P	4.18	5.57	3.32	20.71	4.97	4.52	23.44	3.54	29.76	11.83	88.17	
25	Extracted P	14.80	9.67	7.27	32.27	8.27	7.63	35.33	6.00	45.75	21.54	145.45	166.99
	% of Total P	8.86	5.79	4.35	19.32	4.95	4.57	21.16	3.59	27.40	12.90	87.10	
50	Extracted P	20.85	12.93	8.37	35.00	10.57	11.00	38.27	8.33	49.67	27.27	167.72	194.99
	% of Total P	10.69	6.63	4.29	17.95	5.42	5.64	19.63	4.27	25.47	13.99	86.01	
100	Extracted P	33.43	16.55	9.18	48.53	12.40	13.40	43.60	10.07	54.08	31.65	209.59	241.24
	% of Total P	13.86	6.86	3.81	20.12	5.14	5.55	18.07	4.17	22.42	13.12	86.88	
200	Extracted P	49.63	32.55	11.32	73.20	14.37	15.20	58.00	10.60	73.08	36.29	301.66	337.95
	% of Total P	14.69	9.63	3.35	21.66	4.25	4.50	17.16	3.14	21.62	10.74	89.26	
Average Extracted P		24.91	15.89	8.15	43.57	10.51	10.71	41.57	7.99	52.81	26.65	189.47	216.11
Average % of Total P		10.45	6.90	3.82	19.95	4.95	4.96	19.89	3.74	25.33	12.51	87.49	

Table 16a. The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 240 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	5.53	2.72	4.00	31.33	8.20	7.08	46.60	4.50	48.17	16.70	141.43	158.13
	% of Total P	3.50	1.72	2.53	19.81	5.19	4.48	29.47	2.85	30.46	10.56	89.44	
25	Extracted P	7.25	3.33	5.67	34.92	10.62	9.98	49.37	6.00	56.92	22.29	161.77	184.06
	% of Total P	3.94	1.81	3.08	18.97	5.77	5.42	26.82	3.26	30.92	12.11	87.89	
50	Extracted P	15.25	6.55	6.78	42.30	11.30	12.72	51.33	7.57	59.42	25.65	187.57	213.22
	% of Total P	7.15	3.07	3.18	19.84	5.30	5.97	24.07	3.55	27.87	12.03	87.97	
100	Extracted P	19.85	8.53	9.30	55.38	12.15	14.95	59.00	9.47	71.83	30.92	229.54	260.46
	% of Total P	7.62	3.27	3.57	21.26	4.66	5.74	22.65	3.64	27.58	11.87	88.13	
200	Extracted P	31.50	13.83	10.67	79.25	13.68	18.78	81.60	10.40	96.35	34.75	321.31	356.06
	% of Total P	8.85	3.88	3.00	22.26	3.84	5.27	22.92	2.92	27.06	9.76	90.24	
Average Extracted P		15.88	6.99	7.28	48.64	11.19	12.70	57.58	7.59	66.54	26.06	208.32	234.39
Average % of Total P		6.21	2.75	3.07	20.43	4.95	5.38	25.19	3.24	28.78	11.27	88.73	

Table 16b. The effects of added P on the changes and distribution of P into different P pools after 14 days of DMT-HFO extractions and 240 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P$_i$	HCO_3-P$_i$	HCO_3-P$_o$	OH-P$_i$	OH-P$_o$	D/HCl-P$_i$	C/HCl-P$_i$	C/HCl-P$_o$	H_2SO_4-P$_i$	TOT-P$_o$	TOT-P$_i$	TOT-P
0	Extracted P	6.50	6.50	3.43	25.32	6.22	5.60	31.93	4.27	35.00	13.92	110.85	124.77
	% of Total P	5.21	5.21	2.75	20.29	4.99	4.49	25.59	3.42	28.05	11.16	88.84	
25	Extracted P	17.67	8.33	6.40	28.98	7.88	7.47	32.93	5.67	37.25	19.95	132.63	152.58
	% of Total P	11.58	5.46	4.19	18.99	5.16	4.90	21.58	3.72	24.41	13.08	86.92	
50	Extracted P	25.83	10.67	7.07	31.75	8.78	9.37	34.93	7.33	44.25	23.18	156.80	179.98
	% of Total P	14.35	5.93	3.93	17.64	4.88	5.21	19.41	4.07	24.59	12.88	87.12	
100	Extracted P	40.33	13.77	8.07	44.00	10.67	12.20	39.93	8.73	50.67	27.47	200.90	228.37
	% of Total P	17.66	6.03	3.53	19.27	4.67	5.34	17.48	3.82	22.19	12.03	87.97	
200	Extracted P	60.50	27.43	10.20	63.53	12.07	14.13	56.67	9.27	68.42	31.54	290.68	322.22
	% of Total P	18.78	8.51	3.17	19.72	3.75	4.39	17.59	2.88	21.23	9.79	90.21	
Average Extracted P		30.17	13.34	7.03	38.72	9.12	9.75	39.28	7.05	47.12	23.21	178.37	201.58
Average % of Total P		13.52	6.23	3.51	19.18	4.69	4.86	20.33	3.58	24.09	11.79	88.21	

Table 17a. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 240 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	6.87	2.67	3.87	26.20	7.92	6.20	40.60	3.97	40.40	15.76	122.94	138.70
	% of Total P	4.95	1.93	2.79	18.89	5.71	4.47	29.27	2.86	29.13	11.36	88.64	
25	Extracted P	9.70	3.00	4.43	30.77	9.77	9.33	46.67	5.33	48.33	19.53	147.80	167.33
	% of Total P	5.80	1.79	2.65	18.39	5.84	5.58	27.89	3.19	28.88	11.67	88.33	
50	Extracted P	20.93	5.50	5.50	34.60	10.50	10.30	49.27	6.73	52.73	22.73	173.33	196.06
	% of Total P	10.68	2.81	2.81	17.65	5.36	5.25	25.13	3.43	26.89	11.59	88.41	
100	Extracted P	27.47	7.60	7.53	50.00	11.47	12.53	53.00	8.33	64.33	27.33	214.93	242.26
	% of Total P	11.34	3.14	3.11	20.64	4.73	5.17	21.88	3.44	26.55	11.28	88.72	
200	Extracted P	42.08	11.57	9.50	69.00	12.93	16.53	76.67	9.60	88.67	32.03	304.52	336.55
	% of Total P	12.50	3.44	2.82	20.50	3.84	4.91	22.78	2.85	26.35	9.52	90.48	
Average Extracted P		21.41	6.07	6.17	42.11	10.52	10.98	53.24	6.79	58.89	23.48	192.70	216.18
Average % of Total P		9.05	2.62	2.83	19.21	5.10	5.08	25.39	3.15	27.56	11.09	88.91	

Table 17b. The effects of added P on the changes and distribution of P into different P pools after 28 days of DMT-HFO extractions and 240 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	8.55	4.33	2.07	21.60	5.00	5.50	29.67	3.20	33.00	10.27	102.65	112.92
	% of Total P	7.57	3.83	1.83	19.13	4.43	4.87	26.28	2.83	29.22	9.09	90.91	
25	Extracted P	24.17	6.83	4.63	23.45	7.15	6.93	30.93	4.50	34.00	16.28	126.31	142.59
	% of Total P	16.95	4.79	3.25	16.45	5.01	4.86	21.69	3.16	23.84	11.42	88.58	
50	Extracted P	30.50	7.53	5.33	28.50	7.83	8.37	32.60	6.40	38.50	19.56	146.00	165.56
	% of Total P	18.42	4.55	3.22	17.21	4.73	5.06	19.69	3.87	23.25	11.81	88.19	
100	Extracted P	52.50	11.07	7.40	36.78	8.88	11.13	35.93	7.33	46.00	23.61	193.41	217.02
	% of Total P	24.19	5.10	3.41	16.95	4.09	5.13	16.56	3.38	21.20	10.88	89.12	
200	Extracted P	76.17	21.93	8.63	54.07	11.53	13.00	52.53	8.47	64.83	28.63	282.53	311.16
	% of Total P	24.48	7.05	2.77	17.38	3.71	4.18	16.88	2.72	20.83	9.20	90.80	
Average Extracted P		38.38	10.34	5.61	32.88	8.08	8.99	36.33	5.98	43.27	19.67	170.18	189.85
Average % of Total P		18.32	5.06	2.90	17.42	4.39	4.82	20.22	3.19	23.67	10.48	89.52	

Table 18a. The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 240 days of incubation for Rustenburg soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	8.92	1.87	2.50	21.33	6.80	5.40	38.27	3.27	35.25	12.57	111.04	123.61
	% of Total P	7.22	1.51	2.02	17.26	5.50	4.37	30.96	2.65	28.52	10.17	89.83	
25	Extracted P	12.40	2.30	3.80	25.27	8.43	7.77	42.27	4.23	43.33	16.46	133.34	149.80
	% of Total P	8.28	1.54	2.54	16.87	5.63	5.19	28.22	2.82	28.93	10.99	89.01	
50	Extracted P	25.60	4.77	4.40	30.23	9.57	8.80	45.00	5.93	47.75	19.90	162.15	182.05
	% of Total P	14.06	2.62	2.42	16.61	5.26	4.83	24.72	3.26	26.23	10.93	89.07	
100	Extracted P	36.13	6.80	6.67	43.67	10.50	11.67	48.00	7.27	58.92	24.44	205.19	229.63
	% of Total P	15.73	2.96	2.90	19.02	4.57	5.08	20.90	3.17	25.66	10.64	89.36	
200	Extracted P	53.63	9.13	8.18	59.27	11.00	14.30	71.67	9.03	86.00	28.21	294.00	322.21
	% of Total P	16.64	2.83	2.54	18.39	3.41	4.44	22.24	2.80	26.69	8.76	91.24	
Average Extracted P		27.34	4.97	5.11	35.95	9.26	9.59	49.04	5.95	54.25	20.32	181.14	201.46
Average % of Total P		12.39	2.29	2.48	17.63	4.87	4.78	25.41	2.94	27.20	10.30	89.70	

Table 18b.The effects of added P on the changes and distribution of P into different P pools after 56 days of DMT-HFO extractions and 240 days of incubation for Loskop soil.

Added P (mg kg^{-1})	P-recovery	HFO-P_i	HCO_3-P_i	HCO_3-P_o	OH-P_i	OH-P_o	D/HCl-P_i	C/HCl-P_i	C/HCl-P_o	H_2SO_4-P_i	TOT-P_o	TOT-P_i	TOT-P
0	Extracted P	12.17	3.53	2.05	19.30	4.70	5.30	27.27	2.67	30.75	9.42	98.32	107.74
	% of Total P	11.30	3.28	1.90	17.91	4.36	4.92	25.31	2.48	28.54	8.74	91.26	
25	Extracted P	27.75	3.63	3.50	20.60	6.03	6.30	28.47	4.13	32.17	13.66	118.92	132.58
	% of Total P	20.93	2.74	2.64	15.54	4.55	4.75	21.47	3.12	24.26	10.30	89.70	
50	Extracted P	38.58	5.83	4.77	24.63	7.37	8.27	30.00	5.33	34.17	17.47	141.48	158.95
	% of Total P	24.27	3.67	3.00	15.50	4.64	5.20	18.87	3.35	21.50	10.99	89.01	
100	Extracted P	63.17	8.53	6.00	32.63	8.30	10.60	33.67	6.33	40.33	20.63	188.93	209.56
	% of Total P	30.14	4.07	2.86	15.57	3.96	5.06	16.07	3.02	19.25	9.84	90.16	
200	Extracted P	92.00	17.23	7.77	46.83	10.83	12.73	50.33	8.27	62.67	26.87	281.79	308.66
	% of Total P	29.81	5.58	2.52	15.17	3.51	4.12	16.31	2.68	20.30	8.71	91.29	
Average Extracted P		46.73	7.75	4.82	28.80	7.45	8.64	33.95	5.35	40.02	17.61	165.89	183.50
Average % of Total P		23.29	3.87	2.58	15.94	4.20	4.81	19.61	2.93	22.77	9.72	90.28	

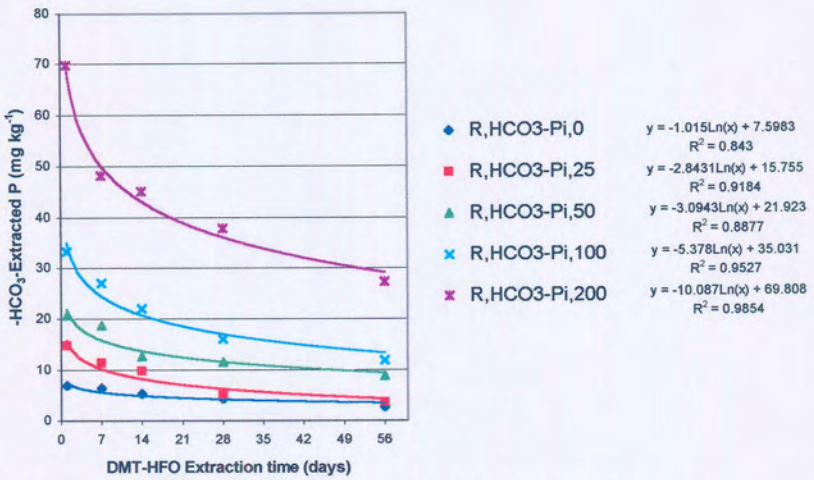

Fig. 3a. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 1 day of incubation of Rustenburg soil

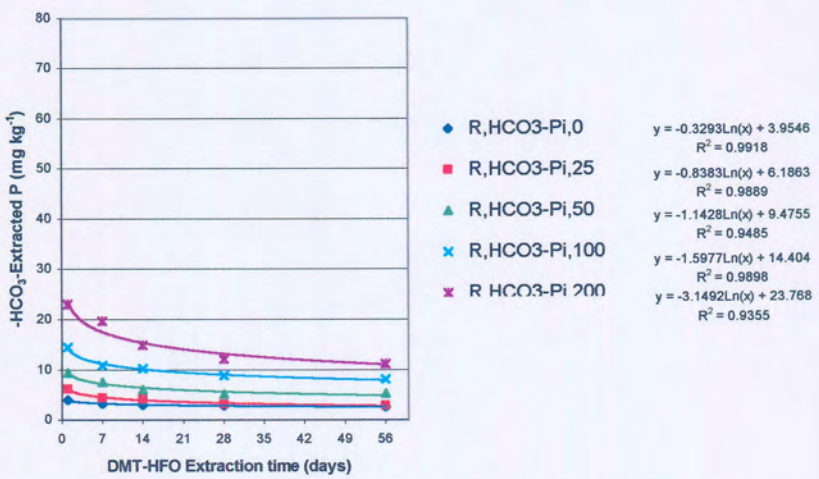

Fig. 3b. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 120 days of incubation of Rustenburg soil

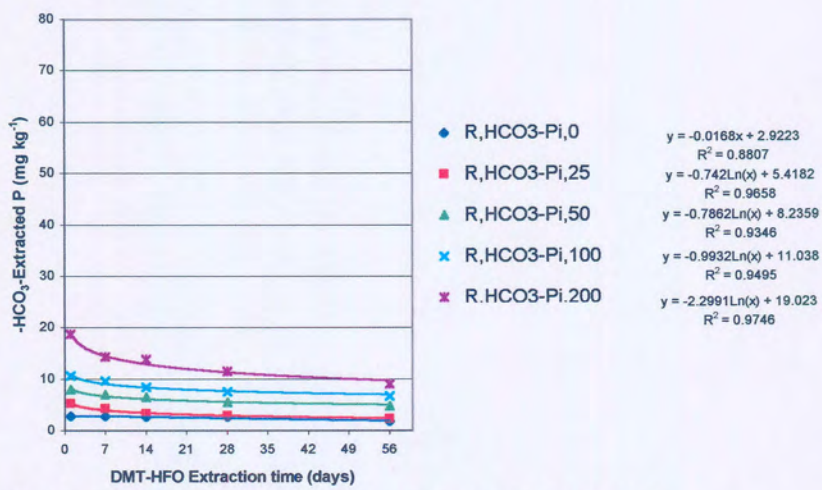

Fig. 3c. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 240 days of incubation of Rustenburg soil

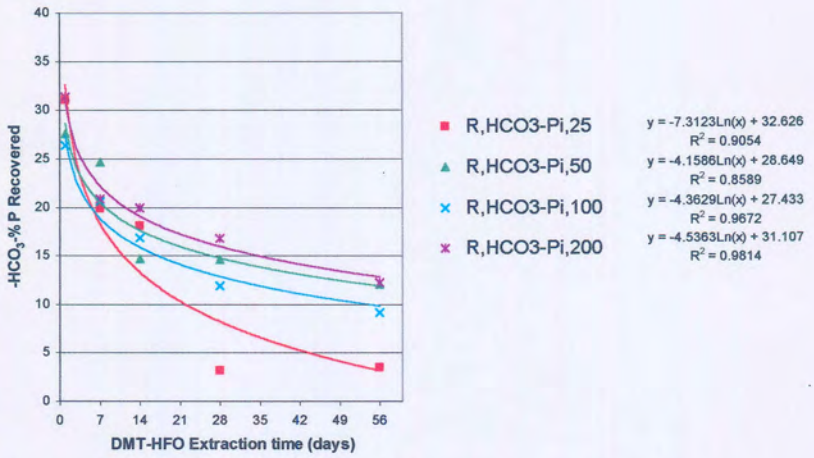

Fig. 3.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 1 day of incubation of Rustenburg soil

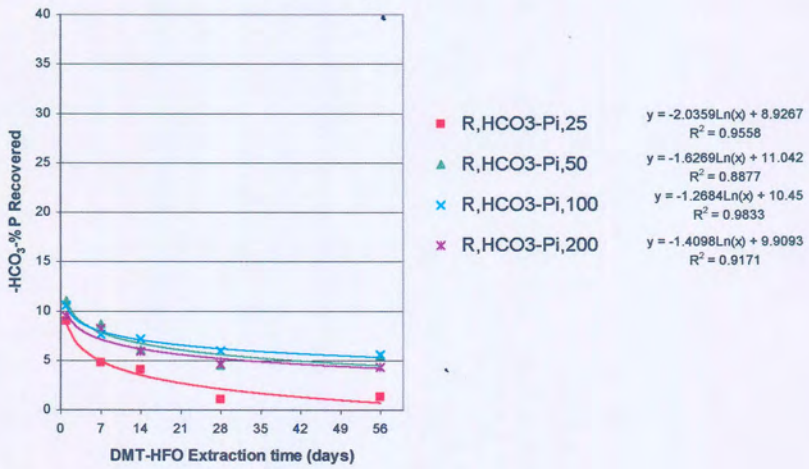

Fig. 3.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 120 days of incubation of Rustenburg soil

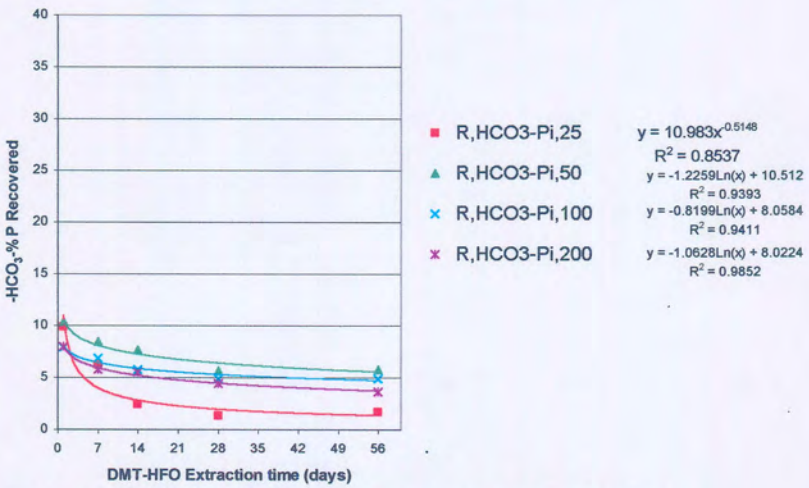

Fig. 3.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 240 days of incubation of Rustenburg soil

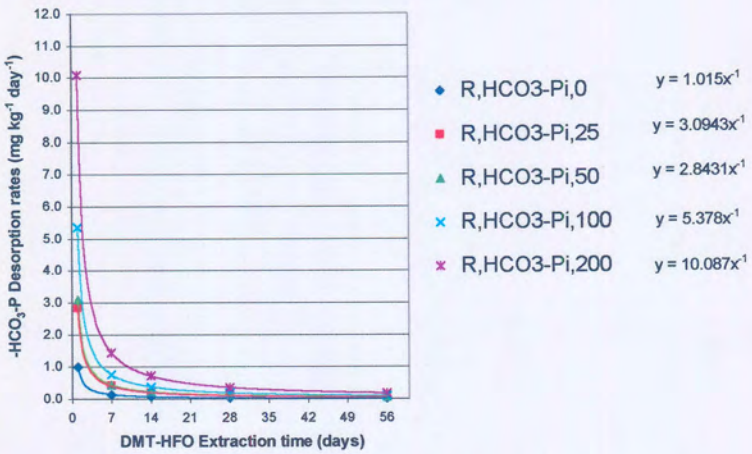

Fig. 3.2a. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

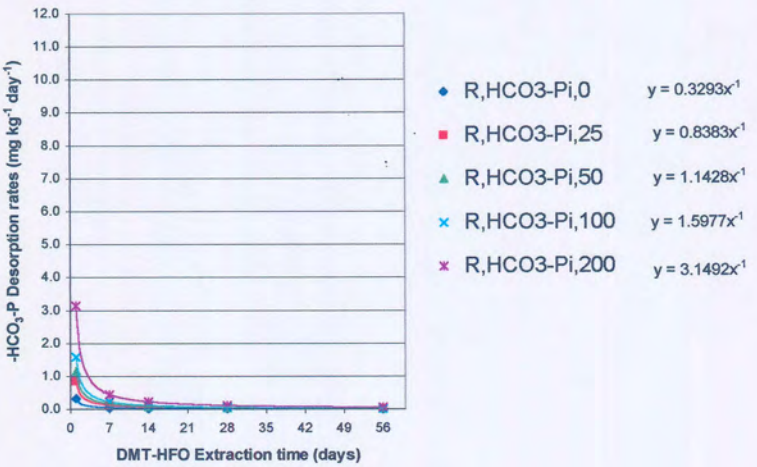

Fig. 3.2b. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

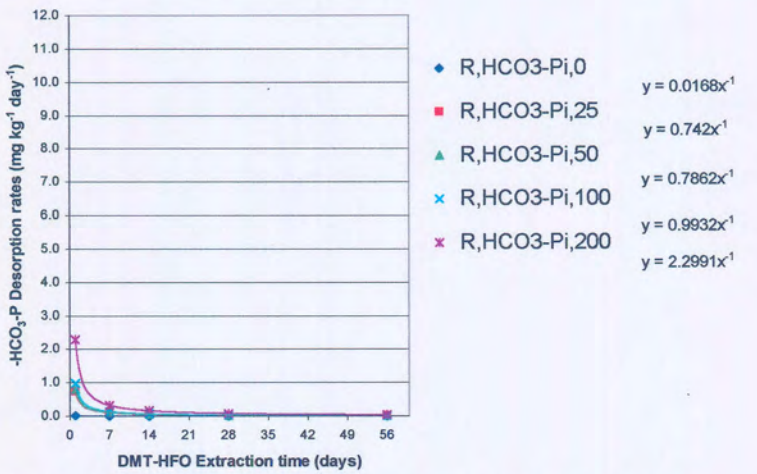

Fig. 3.2c. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

As for the desorption rates from the $-HCO_3$-P_i, pool after 1 day of DMT-HFO extraction, the values reduced from 1.02 and 10.09 (1 day) to 0.02 and 2.30 mg kg^{-1} day^{-1} after 240 days of incubation between the lowest and highest applied P levels respectively. And the desorption rates after 56 days of successive DMT-HFO extractions changed just marginally from 0.03 and 0.20 (1 day) to 0.03 and 0.12 mg kg^{-1} day^{-1} after 240 days of incubation (Figs. 3.2a-c).

Figures 3a-c and 3.1a-c show that there were very negligible changes where no P was added, but there were marked reductions from all the added P levels from the first day of incubation. Reductions from 25 to 100 mg kg^{-1} added P levelled off after 28 days of extractions, but did not drop to the initial levels where no P was added. This indicates that the Rustenburg soil was still able to supply some labile P even after 56 days of extractions, especially with the highest level of applied P. The ability to continue supplying labile P at a constant rate could be due to the influences of both soil organic matter and the clay contents that continued to release the labile P_i via mineralization and desorption processes respectively (Hedley et al., 1982; Bowman and Cole, 1978).

The contributions of $-HCO_3$-P_i extracts to the total soil P pool reduced from 9.80 and 5.20 (1 day) to 2.83 and 2.29 % after 240 days of incubation between 1 and 56 days of successive DMT-HFO-P extractions from the lowest to and highest P levels (Tables 4a-18a).

$-HCO_3$-P_o extracts:

The amounts of the $-HCO_3$-P_o extracted from the Rustenburg soil between 1 and 56 days successive DMT-HFO extractions are shown in Tables 1a-3a, Figures 4a-c, 4.1a-c, and 4.2a-c, and Appendices II No. 7. The data and graphs show that there were only slight changes with added P and just slight decreases were recorded from the different incubation periods following different extraction times. The reductions however did not level off after 56 days of extractions, which could be due to the continued presence of both the soil organic matter and the microbial cells that could

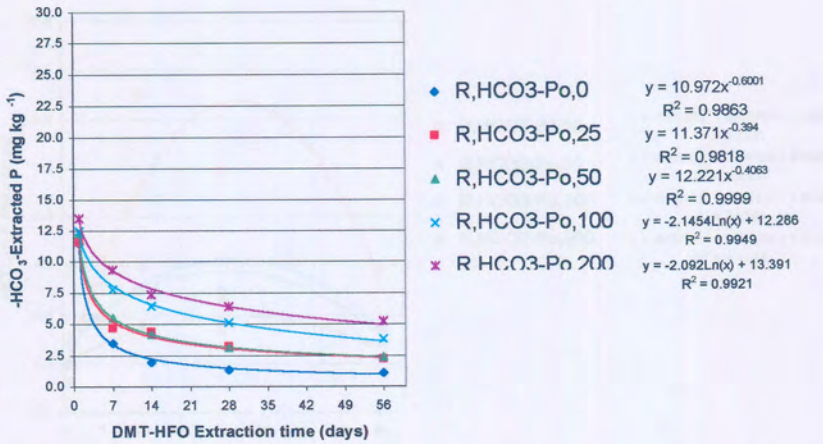

Fig. 4a. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 1 day of incubation of Rustenburg soil

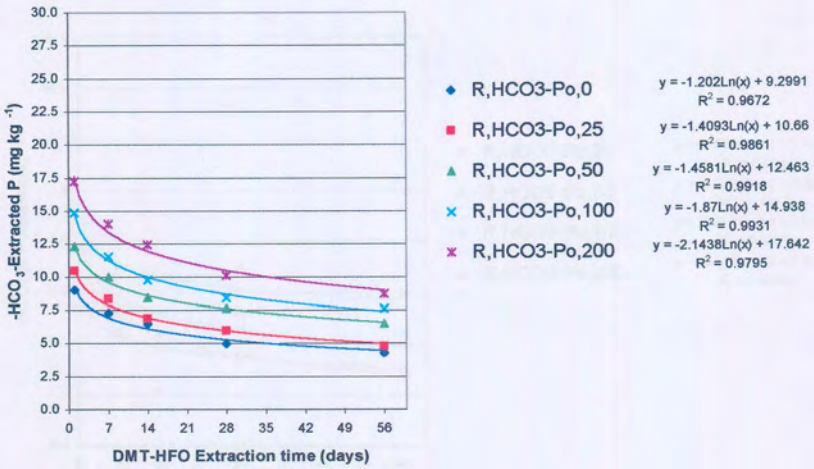

Fig. 4b. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 120 days of incubation of Rustenburg soil

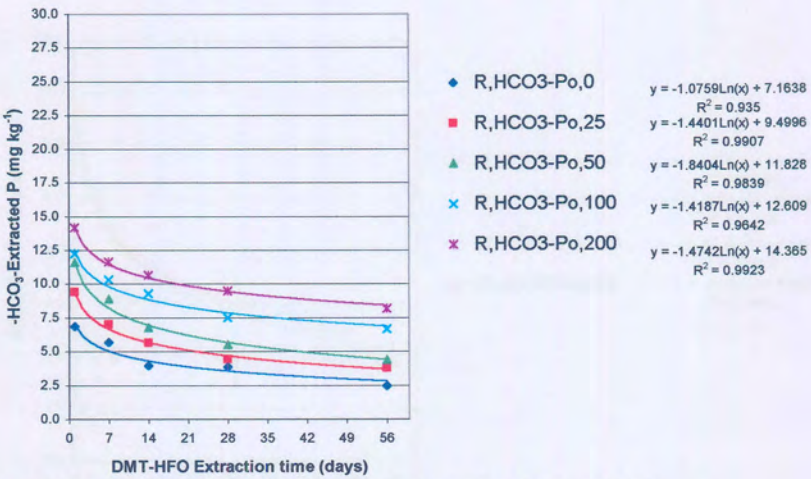

Fig. 4c. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 240 days of incubation of Rustenburg soil

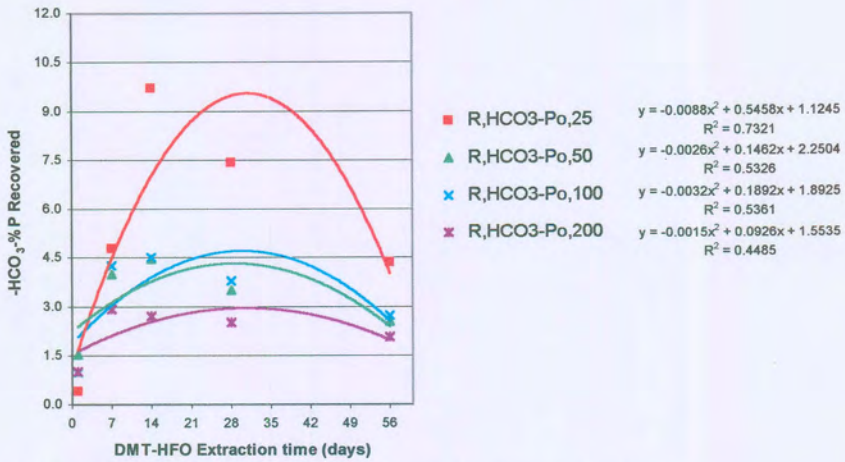

Fig. 4.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 1 day of incubation of Rustenburg soil

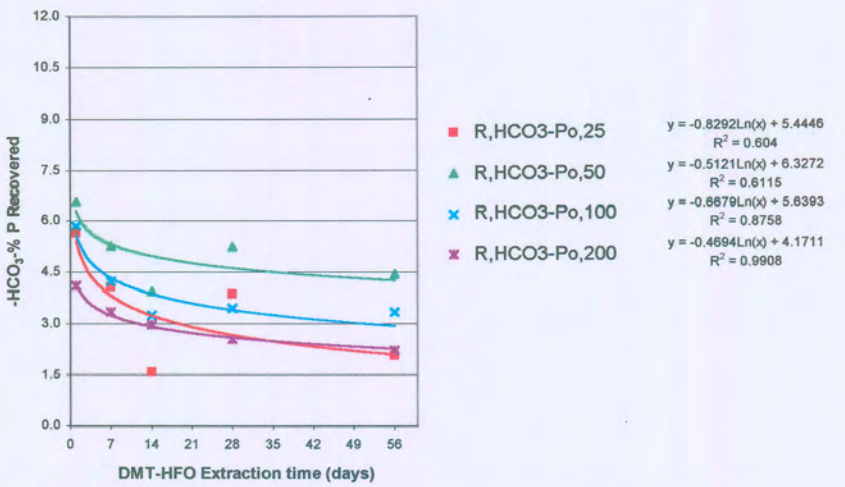

Fig. 4.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 120 days of incubation of Rustenburg soil

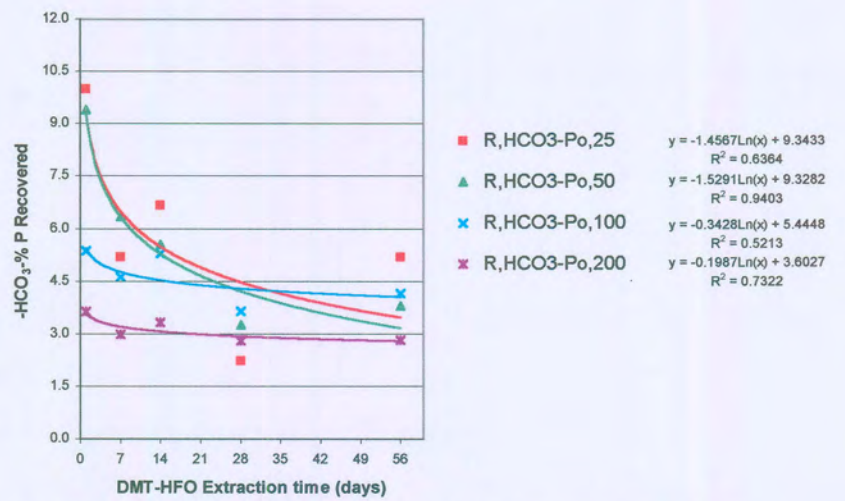

Fig. 4.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 240 days of incubation of Rustenburg soil

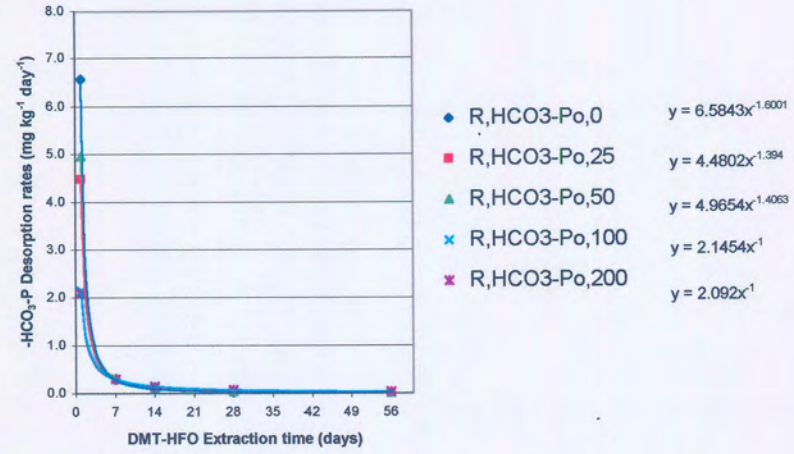

Fig. 4.2a. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

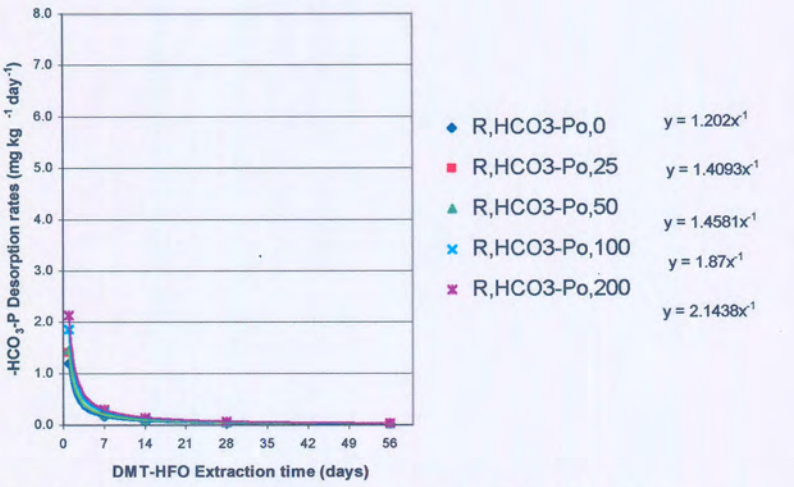

Fig. 4.2b. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

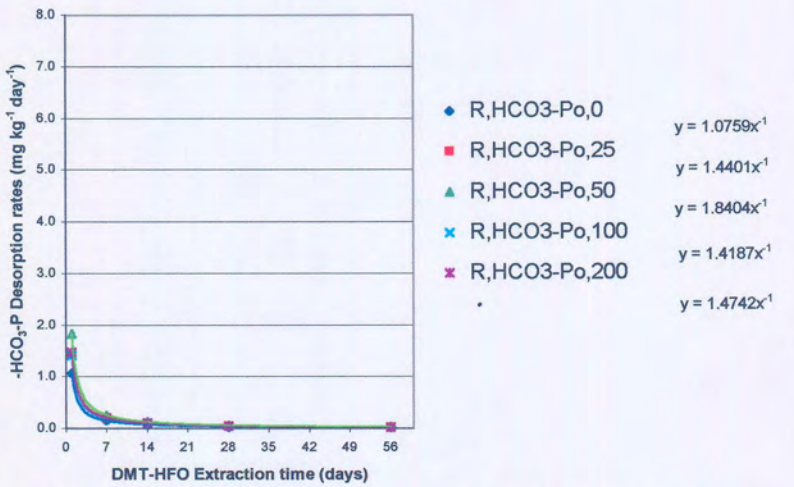

Fig. 4.2c. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

be decomposed over the incubation period (Hedley et al., 1982; Bowman and Cole, 1978).

According to Figures 4.2a-c, desorption rates indicated that this pool became easily depleted as very low release rates were recorded after 14 days of extractions. The desorption rates were low and averaged only about 1.5 mg kg^{-1} day^{-1} after 1 day of extractions and just 0.03 mg kg^{-1} day^{-1} after 56 days of the successive extractions.

2b: (ii). Loskop soil

–HCO_3-P_i extracts:

According to data from Tables 1b-3b, and Figures 5, 5.1 and 5.2, the corresponding values for the –HCO_3-P_i extracts after 1 day of DMT-HFO extraction reduced from 12.27 and 78.00 (1 day) to 9.60 and 44.83 mg kg^{-1} after 240 days of incubation between 0 and 200 mg kg^{-1} of added P respectively. The values after 56 days of successive DMT-HFO extractions dropped from 5.80 and 31.83 (1 day) to 3.53 and 17.23 mg kg^{-1} after 240 days of incubation. The results also showed that the amounts of the –HCO_3-P_i extracts and the percent P recovered from all the levels of applied P decreased as the successive DMT-HFO extraction time and the days of incubation increased as was found with the Rustenburg soil. However, these values are 4 to 3 times as high after 1 day and 3 to 2 times as high after 56 days of extractions between 0 and 200 mg kg^{-1} added P.

The percent P recoveries after one day of DMT-HFO extraction reduced from 26.40 and 32.87 % (1 day) to 11.32 and 17.62 % after 240 days of incubation between 25 and 200 mg kg^{-1} added P respectively. While the percent P recovered after 56 days of successive DMT-HFO extractions decreased from 7.08 and 13.02 (1 day) to 0.40 and 6.85 % after 240 days of incubation. The percent P recovered after 240 days of incubation were slightly higher than those of the Rustenburg soil after 1 day of extraction and almost twice as high with 56 days of extractions, although the values

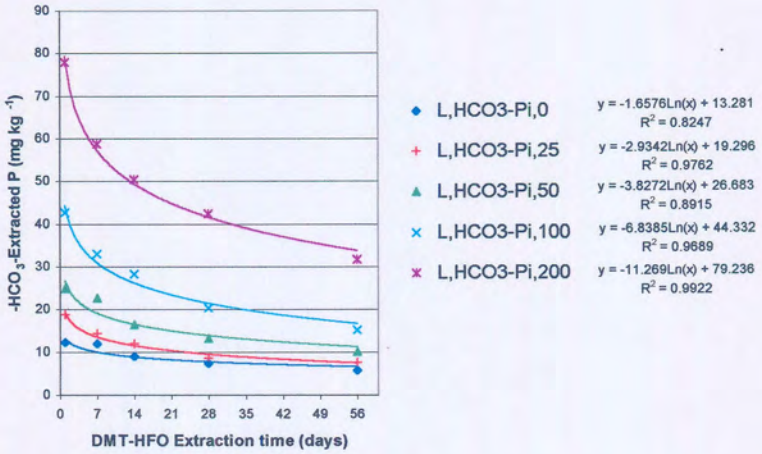

Fig. 5a. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 1 day of incubation of Loskop soil

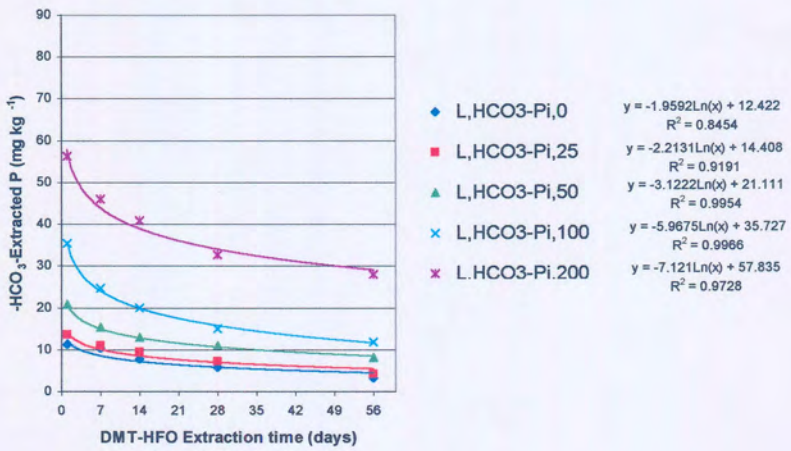

Fig. 5b. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 120 days of incubation of Loskop soil

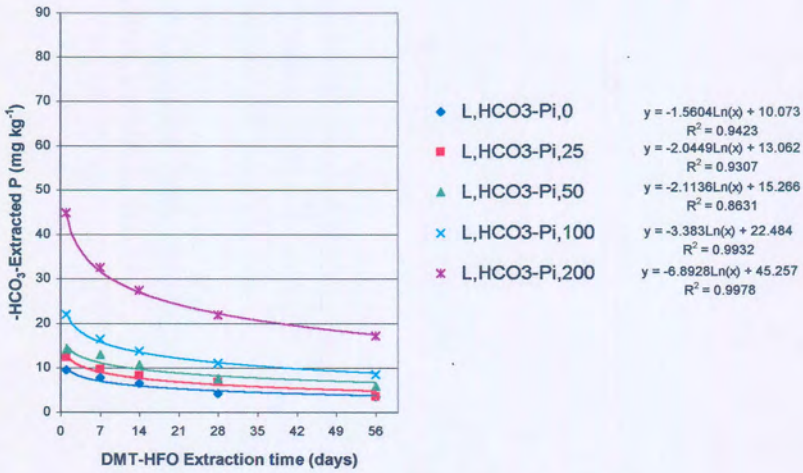

Fig. 5c. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_i after 240 days of incubation of Loskop soil

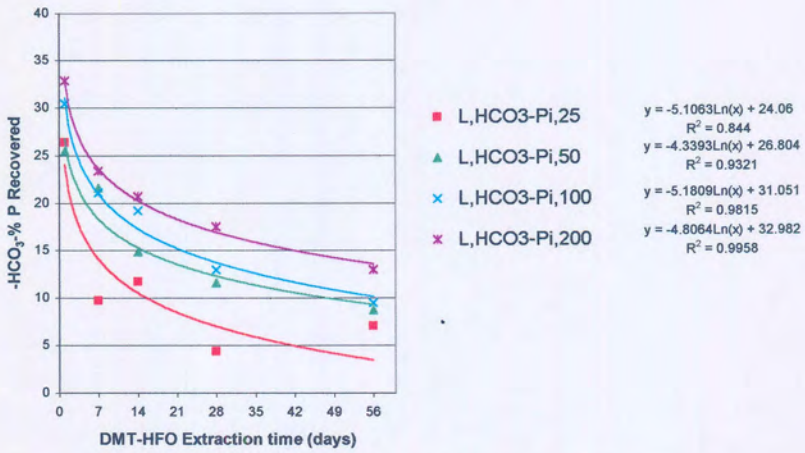

Fig. 5.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 1 day of incubation of Loskop soil

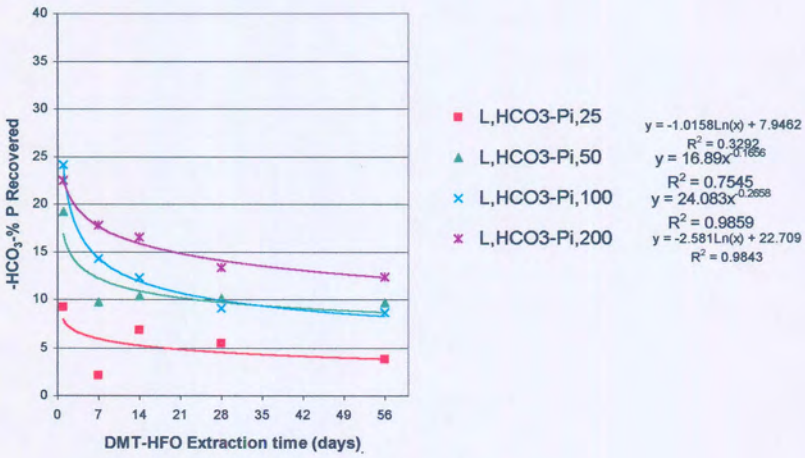

Fig. 5.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 120 days of incubation of Loskop soil

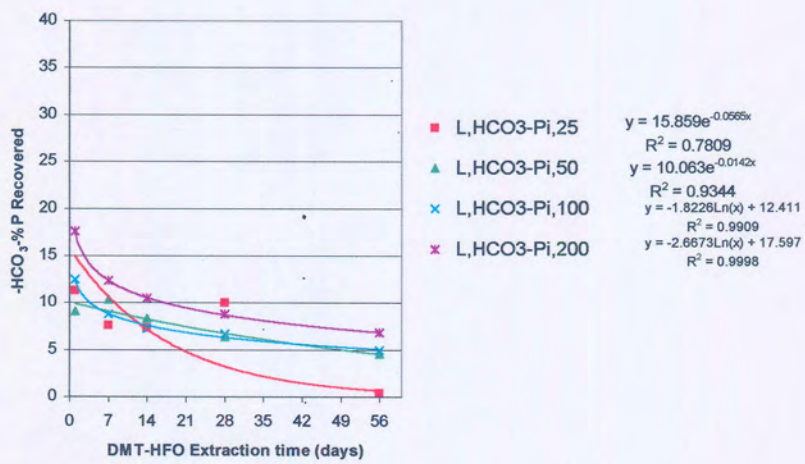

Fig. 5.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 240 days of incubation of Loskop soil

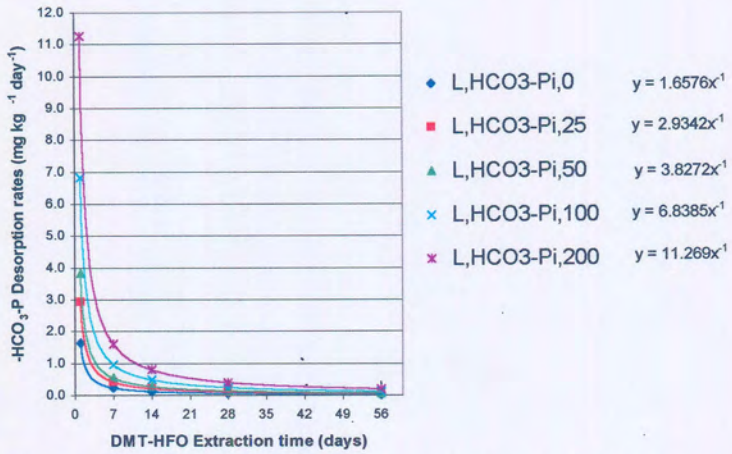

Fig.5.2a. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

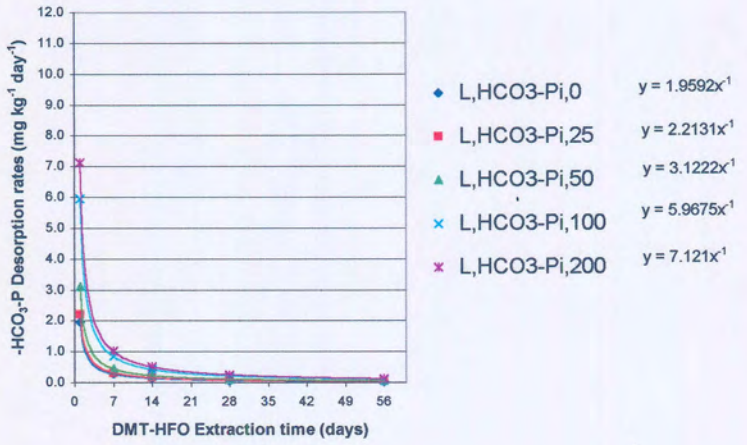

Fig. 5.2b. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

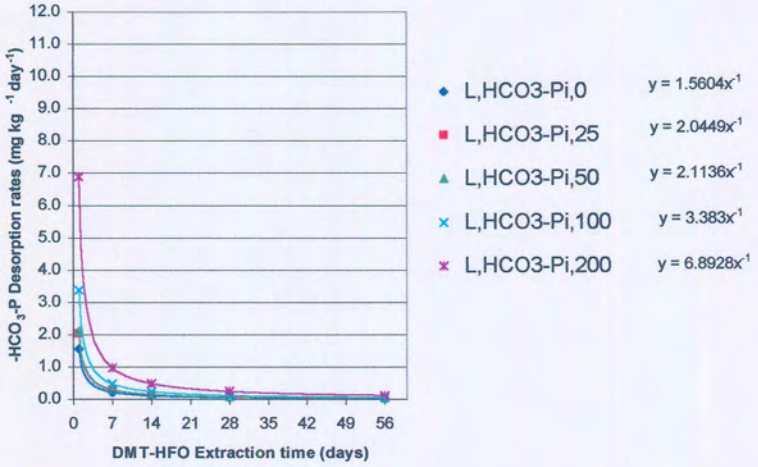

Fig. 5.2c. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

after 1 day of incubation were lower. This is further proof of higher P fixation by the Rustenburg soil.

The desorption rates after one day of DMT-HFO extraction reduced from 1.66 and 11.27 (1 day) to 1.56 and 6.89 mg kg^{-1} day^{-1} after 240 days of incubation between 0 and 200 mg kg^{-1} added P respectively. While the desorption rates after 56 days of successive DMT-HFO-P extractions changed slightly from 0.03 and 0.20 (1 day) to 0.03 and 0.12 mg kg^{-1} day^{-1} after 240 days of incubation (Figs. 5a-c and 5.2a-c). The highest reduction in the P desorption rate took place over the first 14 days of extractions. Further, it should be noted that desorption rates from this P pool were quite identical in both soils.

The contributions of $-HCO_3$-P_i extracts to the total soil P pool dropped from 14.06 and 7.56 (1 day) to 8.06 and 4.87 % after 240 days of incubation between 1 and 56 days of successive DMT-HFO-P extractions respectively (Tables 4b-18b). These values are relatively higher than those of the Rustenburg soil.

Figures 5a-c and 5.1a-c on the other hand, showed some reductions where no P or low levels P were applied, which reached equilibria after 28 of the successive DMT-HFO extractions. However, like the Rustenburg soil losses from the higher levels of added P had also not levelled off completely after 56 days of successive DMT-HFO extractions. The results further revealed that, relatively higher amounts of $-HCO_3$-P_i were extracted from Loskop soil even where no P was added, showing that initially it contained higher $-HCO_3$-extractable P_i.

The differences between the $-HCO_3$-extractable P_i, percent P recoveries, and P desorption rates of the two soils could also be ascribed to the differences in the soil clay and organic matter contents and types. Loskop soil was less buffered as it had relatively lower clay and organic matter contents. And, although it initially had higher $-HCO_3$-P_i it lost a lot more to the DMT-HFO extractable P_i than the Rustenburg soil did. Thus by the end of the successive DMT-HFO-P extractions, Loskop and Rustenburg soils had values that did not differ much (i.e. 7.75 and 4.97

mg kg^{-1} respectively). This indicates that the transformation rate from labile to solution-P (very labile) was higher for the Loskop soil than for the Rustenburg soil. Indiati and Sharpley (1998) also showed that a very close relationship existed between the total amount of P released in the iron oxide-impregnated paper strips successive extraction experiments and $NaHCO_3$-extractable soil P. They concluded that in order to maintain a given rate of P release, a greater available P content ($NaHCO_3$-P_i) was necessary for low P-sorbing soils. This conclusion was consistent with other studies which showed that fine-textured, high P-fixing soils would produce maximum crop yields at lower soil test P levels than coarser-textured and low P-fixing soils (Kamprath, 1978). Lins et al. (1985) showed that inclusion of an estimate of the clay as well as extractable P content, markedly improved the prediction of P fertilizer requirements.

Further, Indiati and Sharpley (1996) showed that the inclusion of a P sorption index that accounts for the overall effect of soil properties affecting P sorption in soil testing programmes for P, could improve fertilizer P recommendations for optimum crop growth in some soils. These properties include clay content and type, iron and aluminium oxide content, surface area, etc.

–HCO_3-P_o extracts:

The corresponding values for the –HCO_3-P_o extracts after the successive DMT-HFO extractions are shown in Tables 1b-3b, and Figures 6, 6.1 and 6.2, and Appendices II No. 19. The graphs for the Loskop soil showed similar reductions to those of Rustenburg between 1 and 120 days of incubation. However, unlike Rustenburg soil, the values remained unchanged after 120 days of incubation. The quantities of –HCO_3-P_o extracted from Rustenburg soil were noticeably higher than for Loskop soil. Also, the percent recovery of the added P from both soils were low, but of particular significance is the fact that the percent P recovered from Loskop soil after 1 day of incubation rose between 1 and 7 days of extraction time and remained relatively constant or increased marginally.

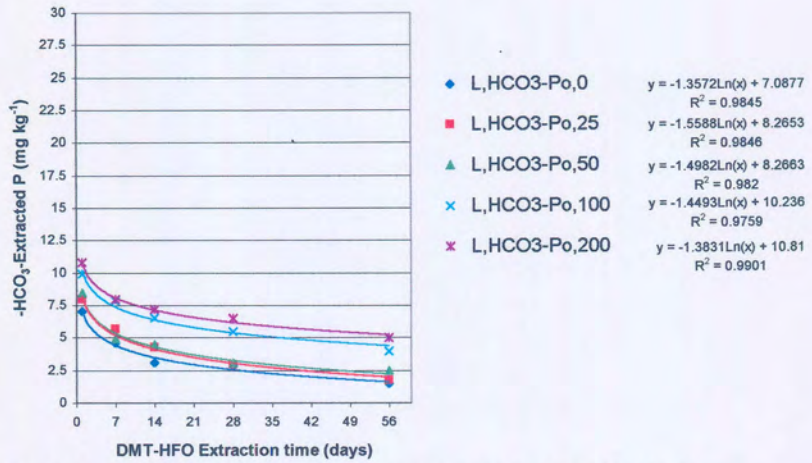

Fig. 6a. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 1 day of incubation of Loskop soil

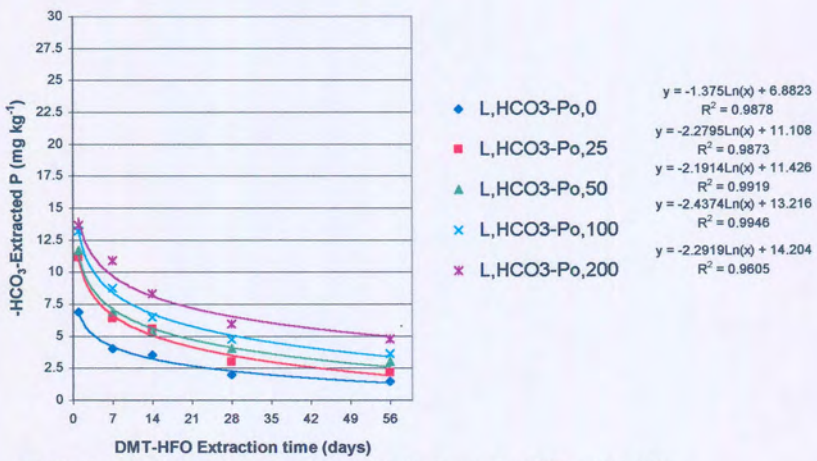

Fig. 6b. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 120 days of incubations of Loskop soil

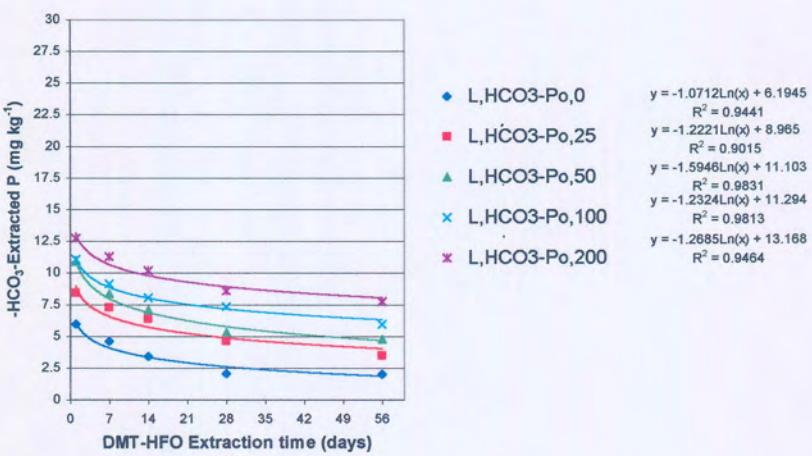

Fig. 6c. The effects of the added P and DMT-HFO extractions on the -HCO_3-extractable P_o after 240 days of incubation of Loskop soil

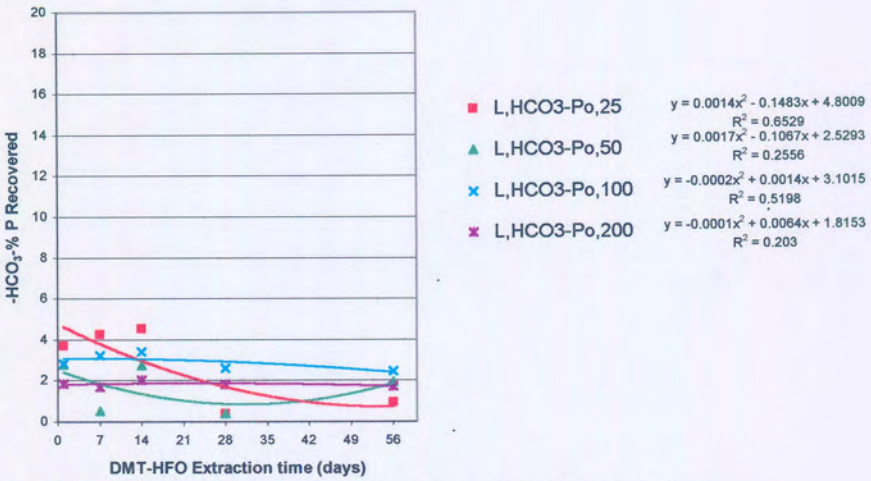

Fig. 6.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 1 day of incubation of Loskop soil

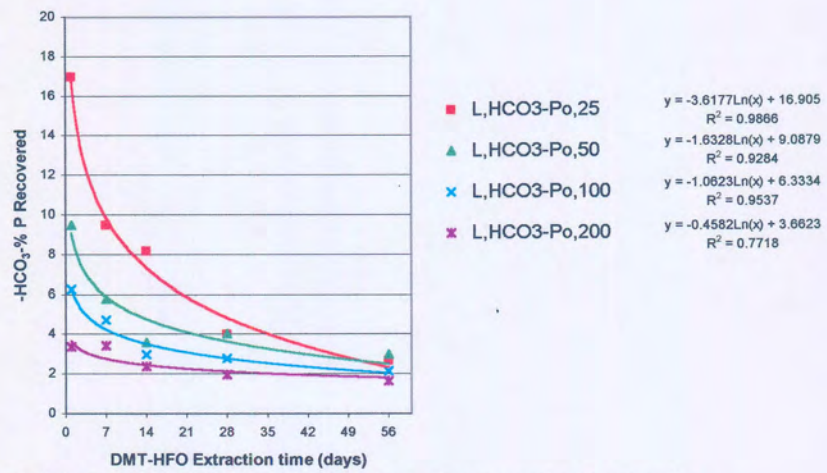

Fig. 6.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 120 days of incubation of Loskop soil

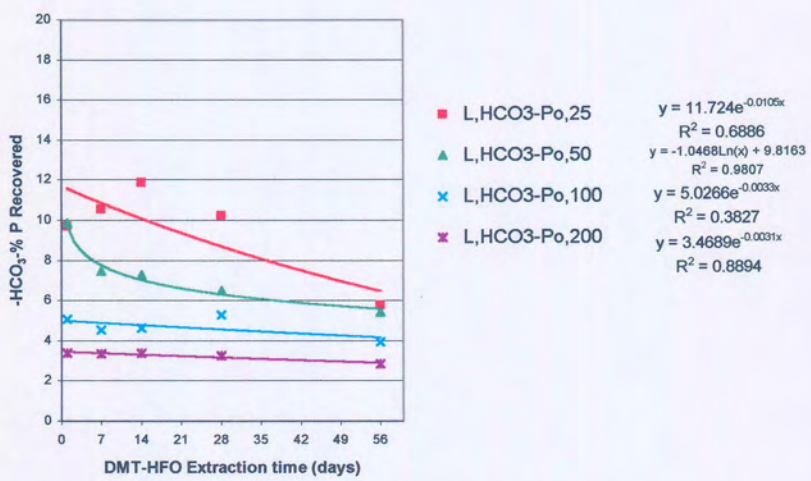

Fig. 6.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -HCO_3-P extractions after 240 days of incubation of Loskop soil

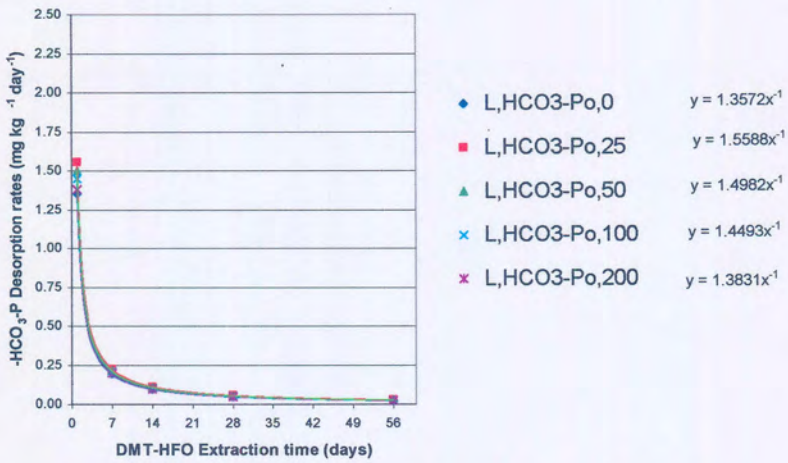

Fig. 6.2a. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

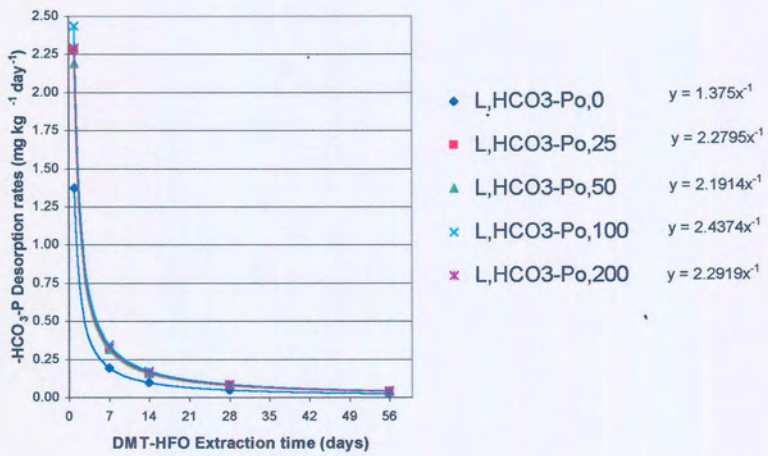

Fig. 6.2b. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

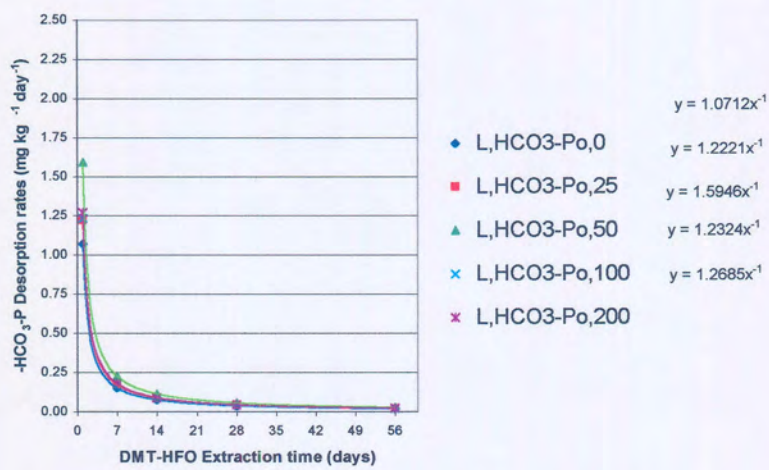

Fig. 6.2c. The effects of the added P and DMT-HFO extractions on -HCO_3-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

The P desorption rates were also marginal and averaged about 1.0 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions and 0.02 mg kg^{-1} day^{-1} after 56 days of the successive DMT-HFO extractions (Figs. 6.2a-c). However there were noticeably higher desorption rates after 120 days of incubation that could show higher rates of P mineralization from this organic P pool.

As it has been noted, changes in the -HCO_3-P_o extracts were moderate showing possibilities of rapid turn over or mineralization of organic materials by soil microbes and deaths of soil microbes that contribute to this fraction of soil P_o. Earlier, Sattell and Morris (1992) had reported that most added P recovered in P_o fractions was probably in the microbial biomass or was P that had reacted directly with soil organic matter or both.

Thus, their contributions to the total P pool were limited with Rustenburg soil contributing approximately 4-2 %, and Loskop soil 3-2 % between 1 and 56 days of DMT-HFO extractions (Tables 4-18).

Total labile P pool (DMT-HFO- and –HCO_3-P extracts)

The DMT-HFO-P_i and –HCO_3-P_i are often used as indicators of plant available P or labile P. The DMT-HFO extracts the solution or freely available soil P, while the labile P_i adsorbed on the soil surfaces is extracted by the sodium bicarbonate (Hedley et al., 1982; Tiessen and Moir, 1993; Freese et al., 1995; Lookman et al., 1995). This labile-P_i fraction accounted for relatively diminishing percentages of the total soil P pool with increasing incubation periods in both soils and therefore it would be unlikely that this fraction alone could continue to supply the P requirements of crops over a prolonged period of time without replenishments from other stable P pools.

As shown in Tables 1a-3a Rustenburg soil on the first day of incubation only about 48 and 52 % could be recovered as labile P between 1 and 56 days of cumulative DMT-HFO extractions. These values were reduced to 15 and 30 % after 240 days of incubation respectively. Corresponding values for Loskop soil were 65 and 70 % on

the first day of incubation and were reduced to 30 and 54 % after 240 days of incubation respectively. However, the noted increases with the cumulative DMT-HFO extractions suggest that the biologically more stable P pools (i.e. adsorbed and insoluble P fractions) play major roles in contributing to the labile P_i pool in order to supply the P requirements of the crops over a prolonged period.

2c: The effects of the added P, incubation time, and successive DMT-HFO extractions on the of adsorbed or slowly labile P pool (0.1M NaOH- and 1M HCl- extracted P)

2c: (i). 0.1M NaOH-extracted P

2c: (i). (a). Rustenburg soil

0.1M NaOH-extracted P_i

The amounts, percent P recovered, and P desorption rates of the 0.1M NaOH-P_i extractable P pool after the successive DMT-HFO extractions from the Rustenburg soil are shown in Tables 1a-3a, and Figures 7, 7.1 and 7.2. This fraction changed highly significantly ($P = 0.01$) with the successive DMT-HFO extractions, the applied P levels, and the incubation periods (Appendices II No. 3).

Unlike the previous P fractions the amounts of the –OH-P_i extracts increased with incubation time but there were highly significant reductions due to the extraction times, showing that this fraction was possibly a major contributor to the labile P pool. Thus, it is noted that after 1 day of DMT-HFO extraction the values varied from 30.13-55.17 (no P added) and 90.47-106.17 mg kg^{-1} (200 mg P kg^{-1}) for 1-240 days of incubation. The values after 56 days of successive DMT-HFO extractions were 10.77-21.33 (no P added) to 42.27-59.27 mg kg^{-1} (200 mg P kg^{-1}) for 1-240 days of incubation.

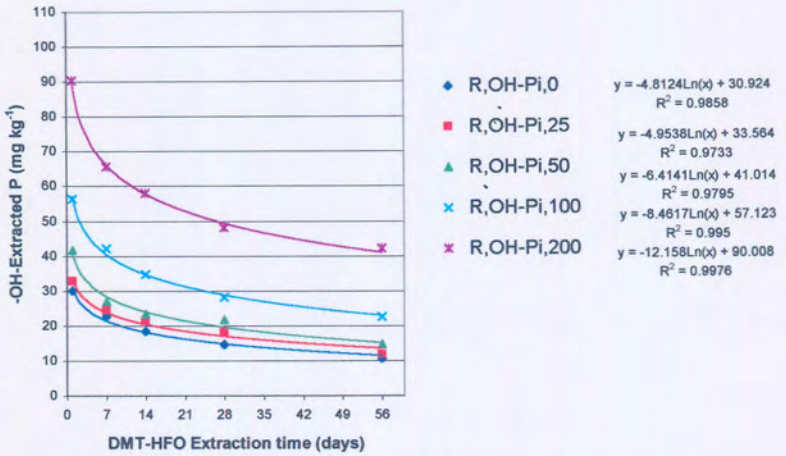

Fig. 7a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 1 day of incubation of Rustenburg soil

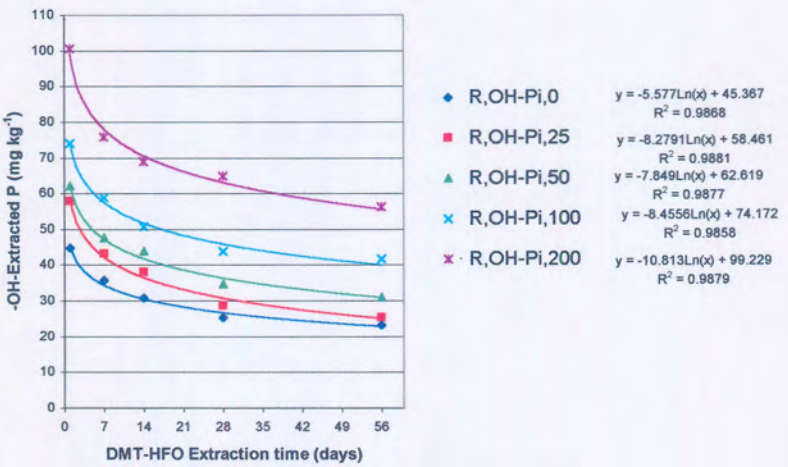

Fig. 7b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 120 days of incubation of Rustenburg soil

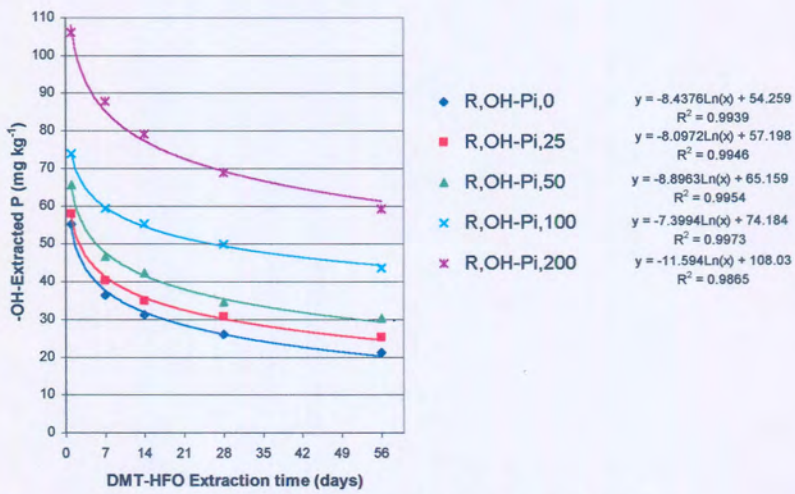

Fig. 7c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 240 days of incubation of Rustenburg soil

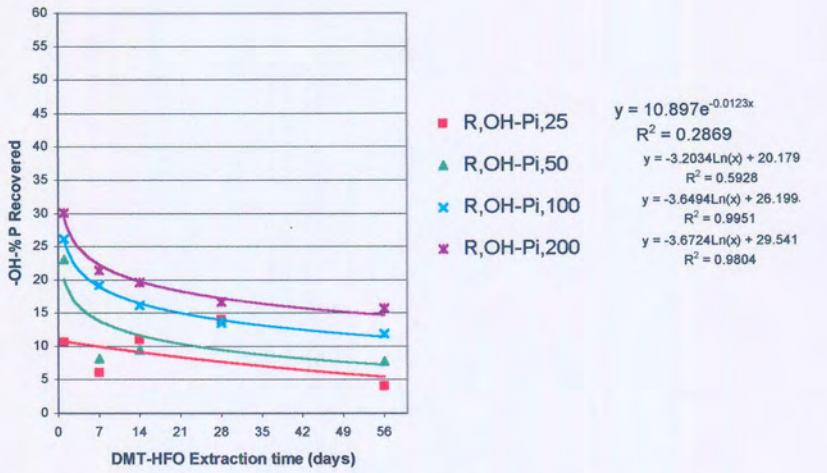

Fig. 7.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 1 day of incubation of Rustenburg soil

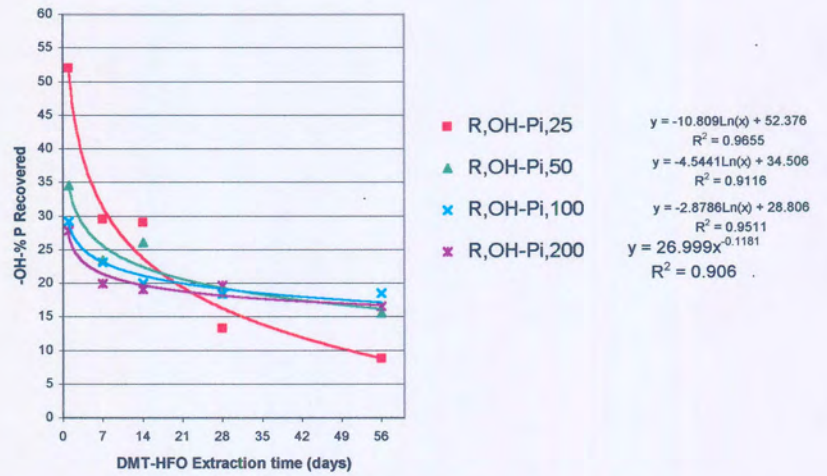

Fig. 7.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered

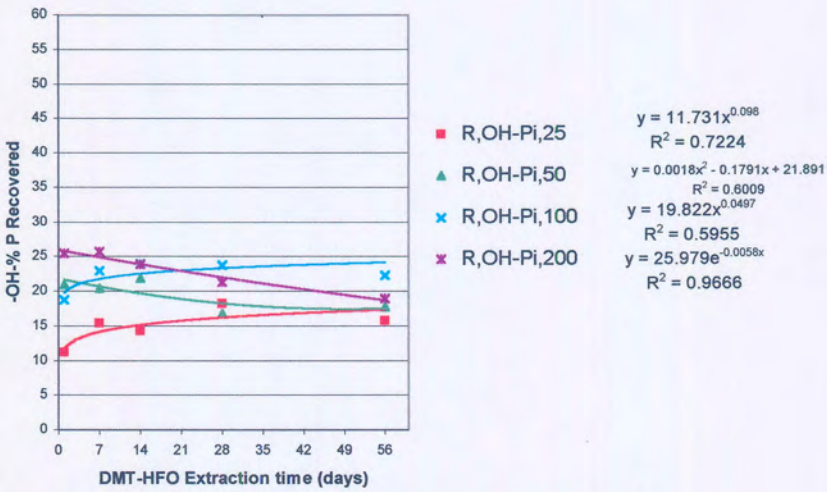

Fig. 7.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered

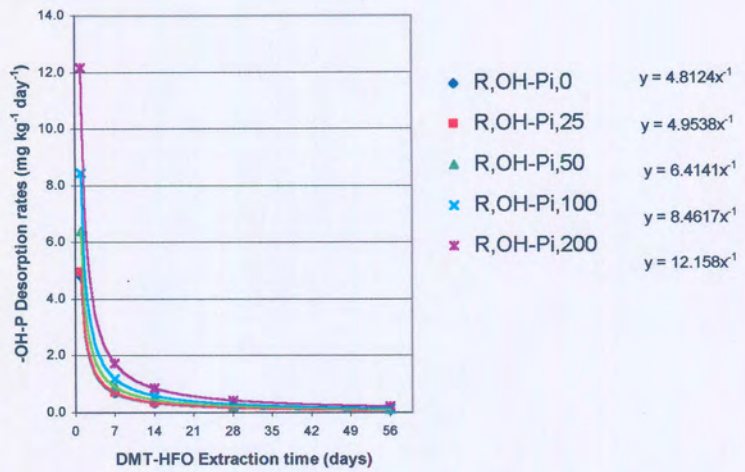

Fig. 7.2a. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

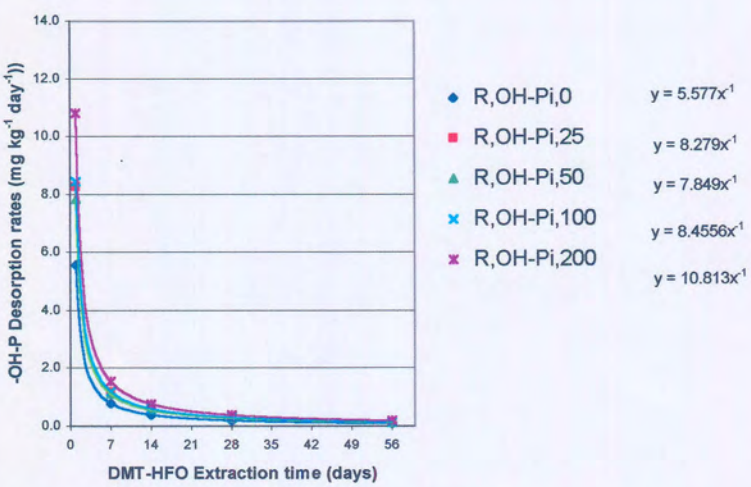

Fig. 7.2b. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

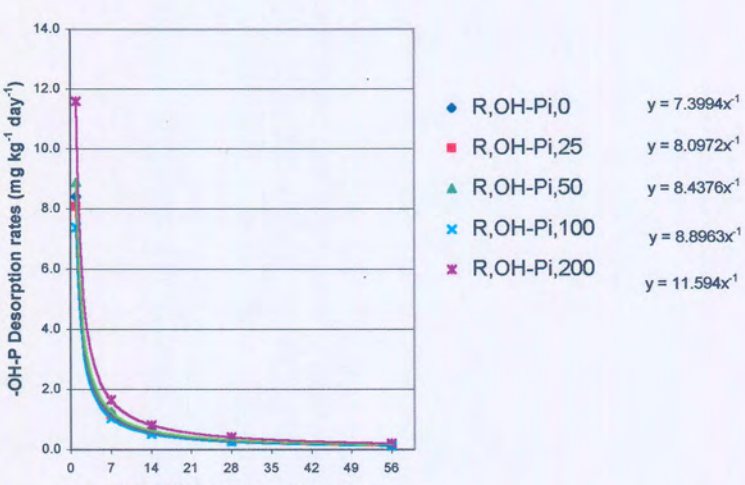

Fig. 7.2c. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

The graphs (Figs. 7a-c) show marked changes from the different rates of the added P after successive extractions from different incubation times. There was very high adsorption of the added P in this pool just on the first day of incubation with 100-200 mg kg^{-1} added P, which was subsequently extracted as –OH-P_i. For example, with 200 mg P kg^{-1} an increase (adsorption) of 48.20 mg kg^{-1} was recorded after one day, thereafter the rates remained more or less constant (46.90 mg kg^{-1}) up to the end of the incubation time.

The percent recovery of the added P after 1 day of DMT-HFO extraction showed no change with low levels of added P (10.68-11.24 %) but the increases were almost twice as high with the highest levels of the added P (13.53-25.50 %) between 1 and 240 days of incubation. The percent P recovered after 56 days of successive DMT-HFO extractions did not increase much with higher levels of the added P (15.75-18.97 %) but over 10 % increase was recorded with the lowest P level (4.12-15.76 mg kg^{-1}) between 1 and 240 days of incubation (Figs. 7.1a-c).

The P desorption rates after 1 day of DMT-HFO extraction were twice as high as where no P was added (4.81-8.44 mg kg^{-1} day^{-1}) between 1 and 240 days of incubation but the desorption rates were almost unchanged with the highest levels of the added P (12.16-11.59 mg kg^{-1} day^{-1}). The desorption rates after 56 days of successive DMT-HFO extractions did not increase much with all levels of the added P (0.09-0.15 mg kg^{-1} day^{-1}) with no P added and 0.22-0.21 mg kg^{-1} day^{-1} with the highest P between 1 and 240 days of incubation (Figs. 7.2a-c).

The contributions of the –OH-P_i extracts to the total P pool between 1 and 56 days of successive DMT-HFO extractions increased from 18.42 and 10.80 % (1 day) to 24.34 and 19.21 % after 240 days of incubation, still showing the importance of this pool as a reservoir for the labile P pool (Tables 4a-18a).

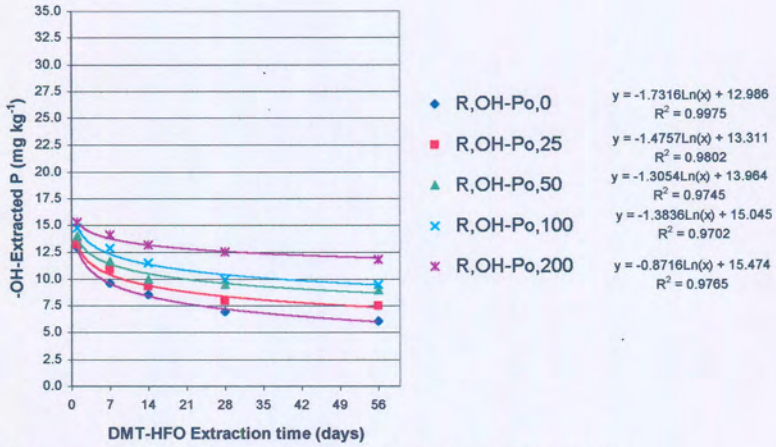

Fig. 8a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 1 day of incubation of Rustenburg soil

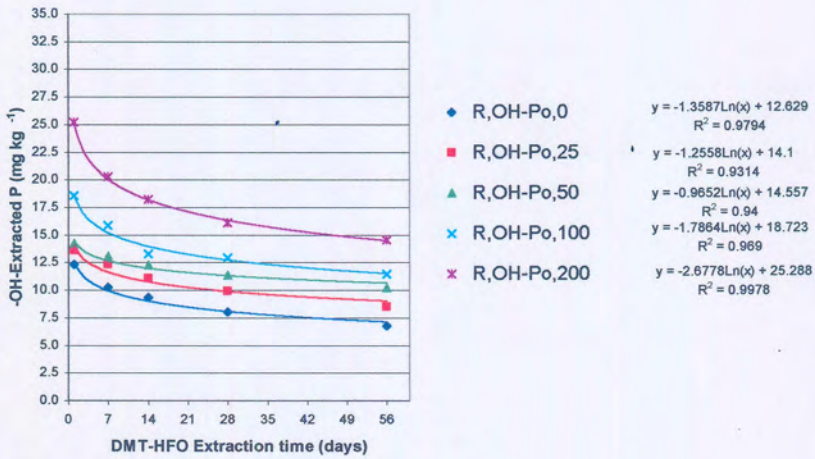

Fig. 8b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 120 days of incubation of Rustenburg soil

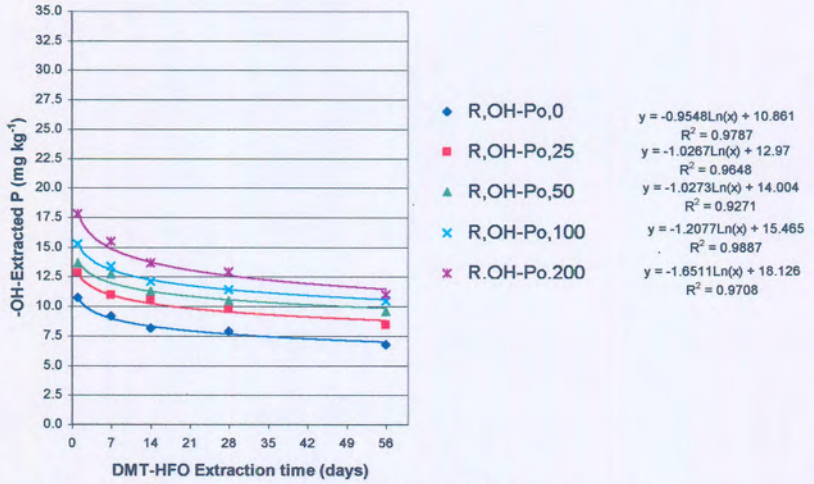

Fig. 8c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 240 days of incubation of Rustenburg soil

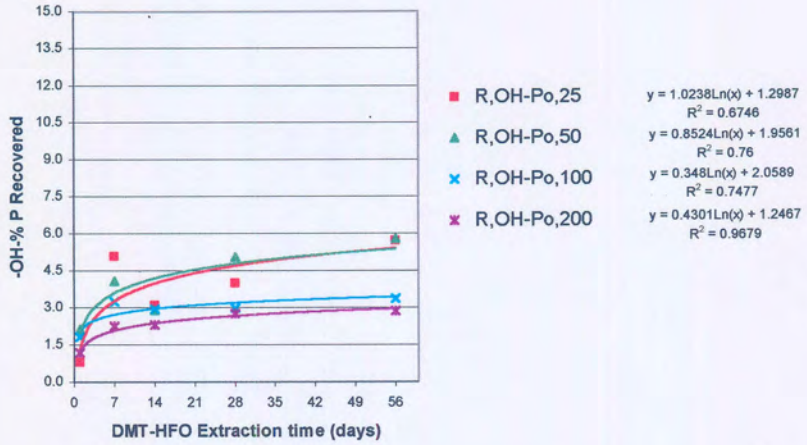

Fig. 8.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 1 day of incubation of Rustenburg soil

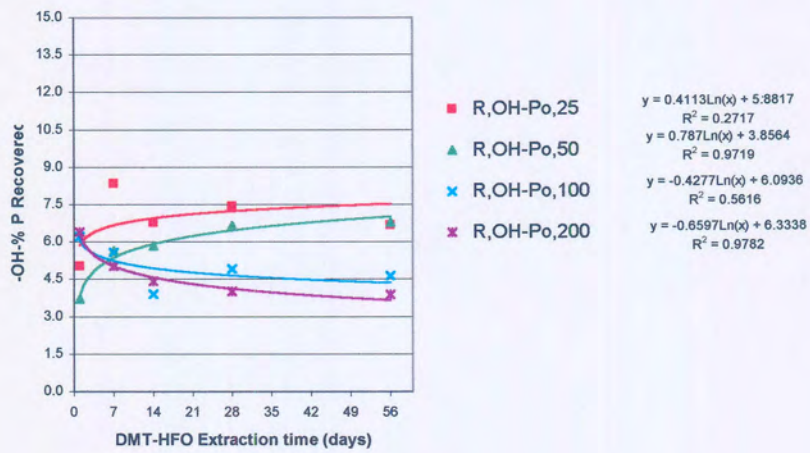

Fig. 8.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 120 days of incubation of Rustenburg soil

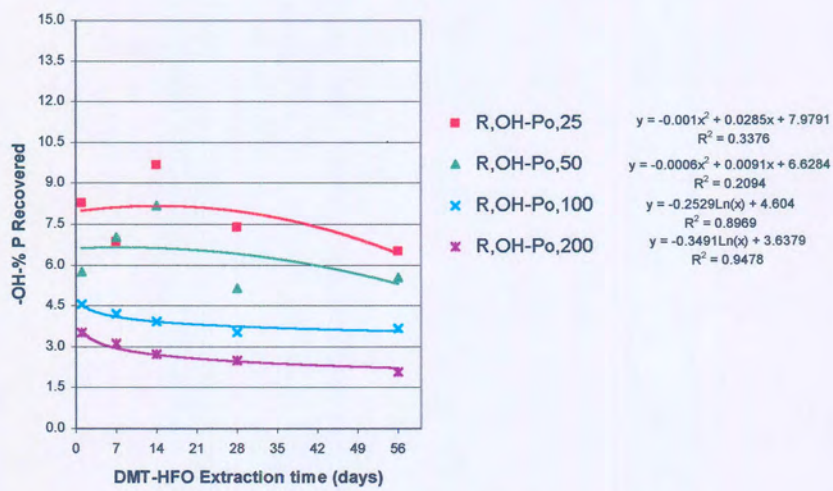

Fig. 8.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 240 days of incubation of Rustenburg soil

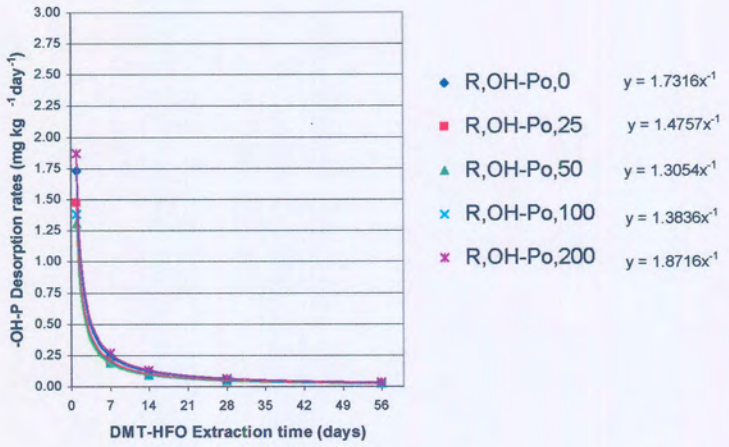

Fig. 8.2a. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

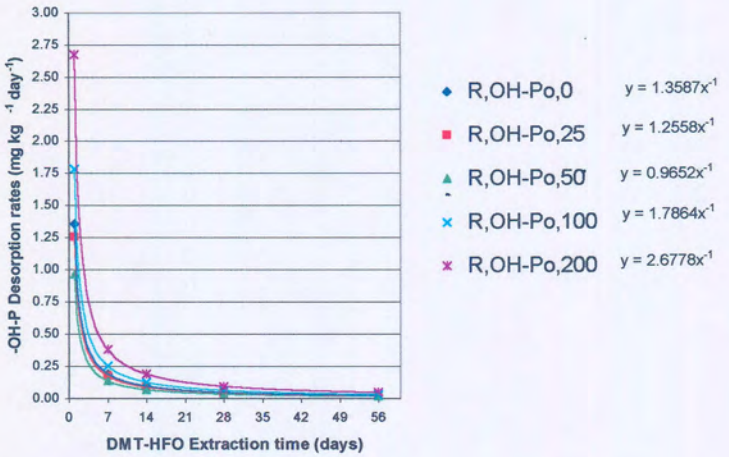

Fig. 8.2b. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

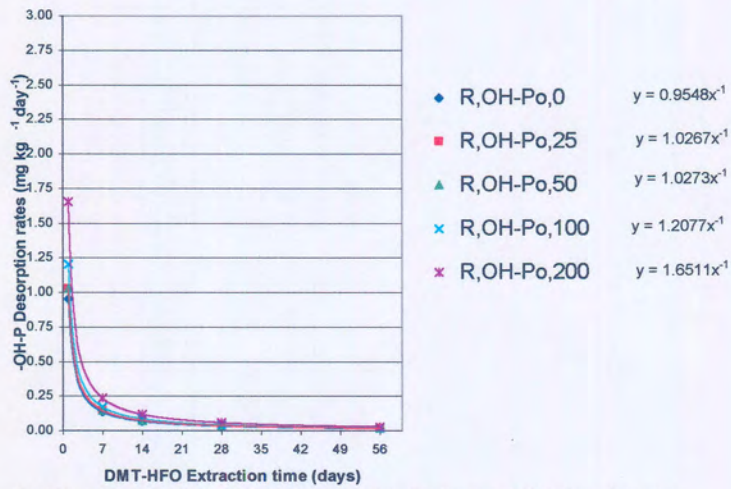

Fig. 8.2c. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

0.1M NaOH-P_o extracts:

The data in Tables 1a-3a, and Figures 8, 8.1 and 8.2 show that the changes in the 0.1M NaOH-P_o extracts were also significant (Appendices II No. 8) with the successive DMT-HFO extractions.

However, the amounts of the –OH-P_o extracted did not change much with all the treatment levels. Thus, after day 1 of DMT-HFO extraction the amounts remained stable from 12.15-10.75 (no P added) and 15.30-17.80 mg kg^{-1} (200 mg P kg^{-1}) between 1 and 240 days of incubation respectively. Similarly the amounts after 56 days of successive DMT-HFO extractions stabilized between 6.10-6.80 (no P added) and 11.83-11.00 mg kg^{-1} (200 mg kg^{-1}) after 1-240 days of incubation. The highest point reached after 120 days of incubation would indicate the equilibrium between the –OH-P_o and the mineralization processes that limited further increases with the applications of inorganic P (Tables 1a-3a; Figs. 8.1a-c). Accordingly the percent P recovery of the –OH-P_o extracts also did not change much with the treatments applied. After 1 day of the DMT-HFO extraction the percent P recovered was very low, ranging from about 1-3 % and after 56 days of the successive DMT-HFO extractions the recovery averaged 5-2 % from the lowest to the highest applied P between 1 and 240 days of incubation (Figs. 8.1a-c).

The P desorption rates were also relatively low averaging about 1.0 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions and 0.02 mg kg^{-1} day^{-1} after 56 days of extractions (Figs. 8.2a-c). However as with the bicarbonate P_o there were noticeably higher desorption rates after 120 days of incubation that could show higher rates of P mineralization from this organic P pool. The –OH-extracted P_o contribution to the total P pool after the successive DMT-HFO extractions were again low and remained stable at about 5 % (Tables 4a-18a).

2c: (i). (b). Loskop soil

–OH-P_i extracts:

For the Loskop soil, the corresponding amounts of the –OH-P_i extracts after 1 day of DMT-HFO extraction were lower than for the Rustenburg soil, and ranged from 25.33-32.93 and 65.93-86.53 mg kg^{-1} (0 and 200 mg kg^{-1} added P) between 1 and 240 days of incubation. The amounts after 56 days of successive DMT-HFO extractions were also lower ranging from 13.40-19.30 and 39.45-46.83 mg kg^{-1} (0 and 200 mg kg^{-1}) between 1 and 240 days of incubation (Tables 1b-3b; Figs. 9a-c).

The response curves from all the applied P were not so high as compared to the Rustenburg soil (Figs. 9a-c). For example, with 200 mg kg^{-1} after day 1 of DMT-HFO extraction the values varied from 65.93 - 86.53 mg kg^{-1} (compared to 90.47 - 106.17 mg kg^{-1} of Rustenburg soil) between 1 and 240 days of incubation respectively. The 200 mg kg^{-1} curve after the first day of incubation was almost a straight line, indicating constant desorption of the added P.

Unlike for the Rustenburg soil, the percent P recovered remained stable for both low and high levels of the applied P. Thus, after 1 day of DMT-HFO extraction the values were 11.20-8.62 % and 20.30-26.80 % (25 and 200 mg kg^{-1} added P) and after 56 days of successive DMT-HFO extractions they remained stable at 5.28–5.20 % and 13.03-13.77 % (25 and 200 mg kg^{-1}) between 1 and 240 days of incubation respectively (Figs. 9.1a-c).

Further, unlike for the Rustenburg soil, the –OH-P_i desorption rates remained stable for low levels of the applied P but increased with the highest levels of applied P. Thus, after 1 day of DMT-HFO extraction the values were 2.92-3.47 mg kg^{-1} day^{-1} (no P added) and 6.25-10.02 mg kg^{-1} day^{-1} (200 mg kg^{-1}) between 1 and 240 days of incubation. After 56 days of successive DMT-HFO extractions the values remained almost stable at 0.05-0.06 and 0.11-0.18 mg kg^{-1} day^{-1} (0 and 200 mg kg^{-1}) between 1 and 240 days of incubation respectively (Figs. 9.2a-c).

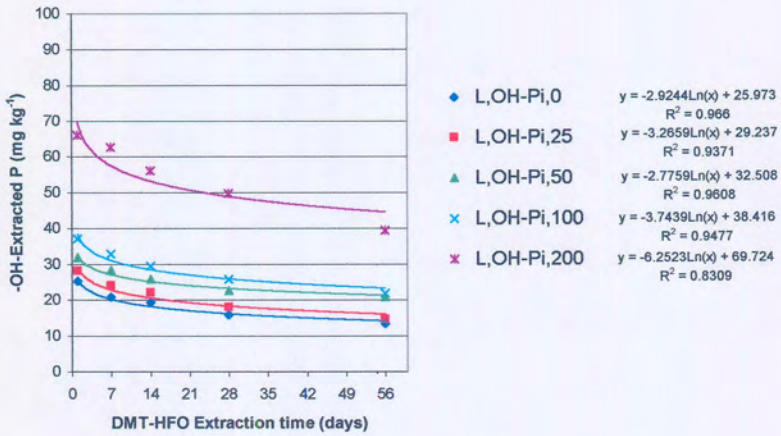

Fig. 9a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 1 day of incubation of Loskop soil

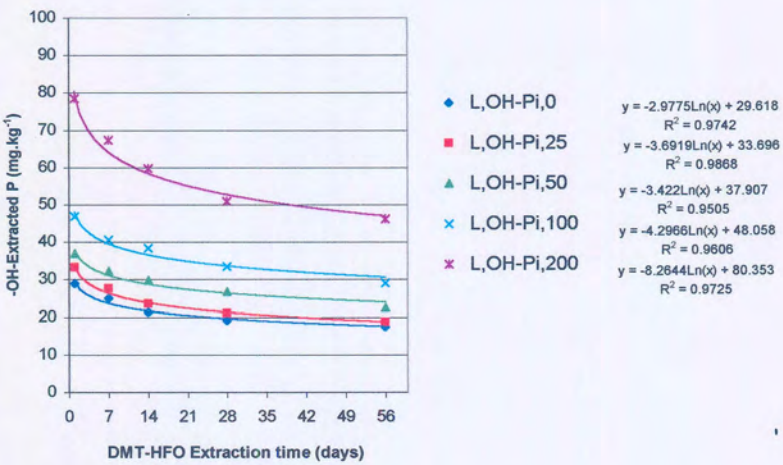

Fig. 9b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 120 days of incubation of Loskop soil

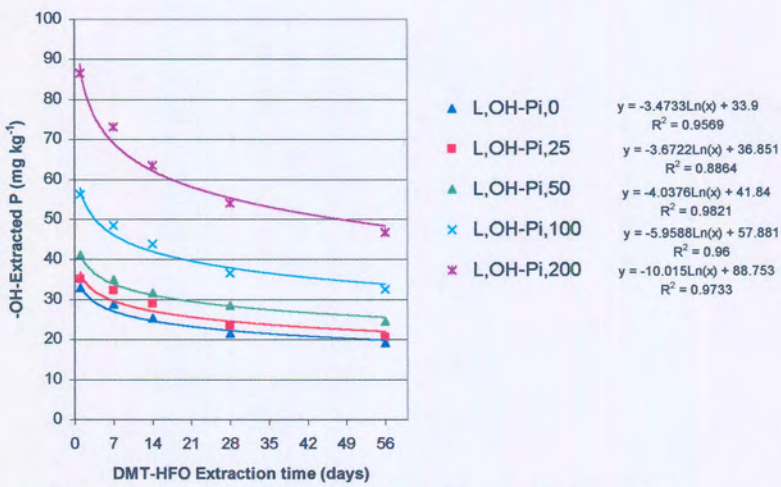

Fig. 9c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 240 days of incubation of Loskop soil

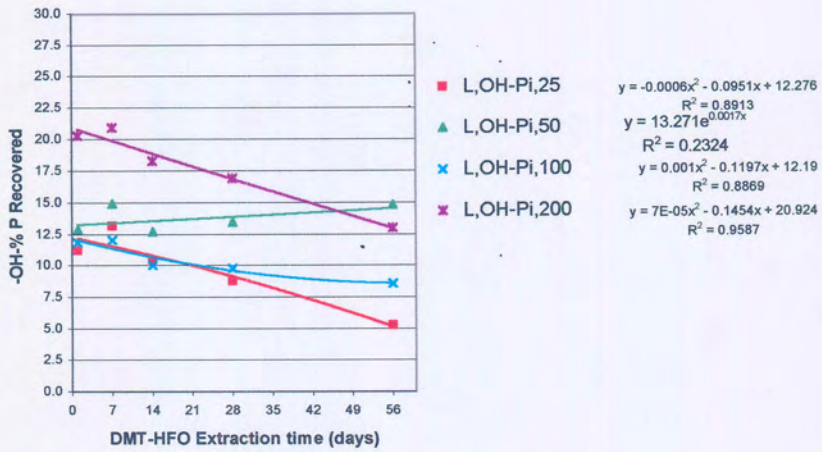

Fig. 9.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 1 day of incubation of Loskop soil

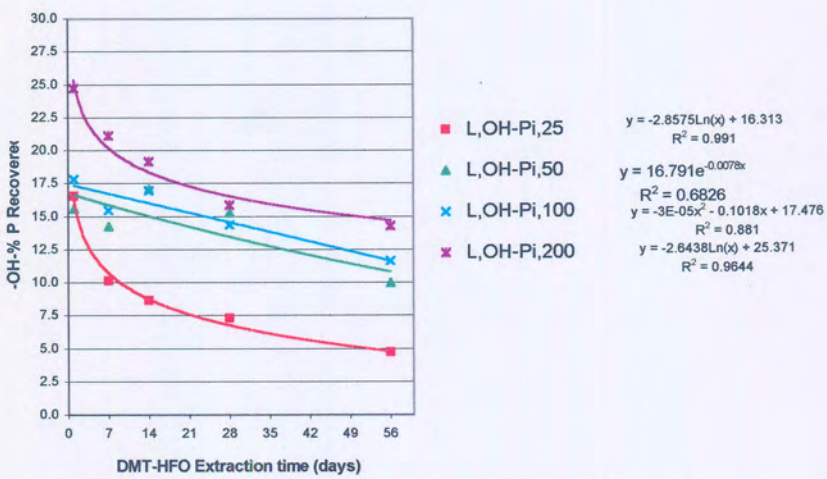

Fig. 9.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 120 days of incubation of Loskop soil

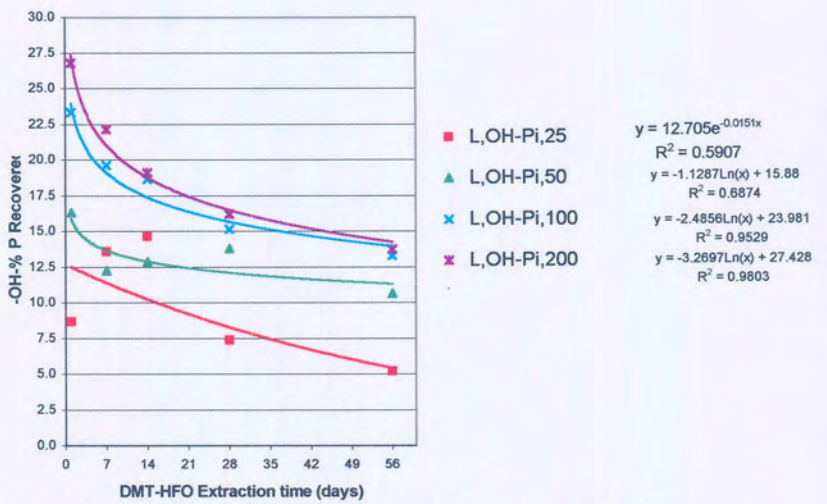

Fig. 9.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 240 days of incubation of Loskop soil

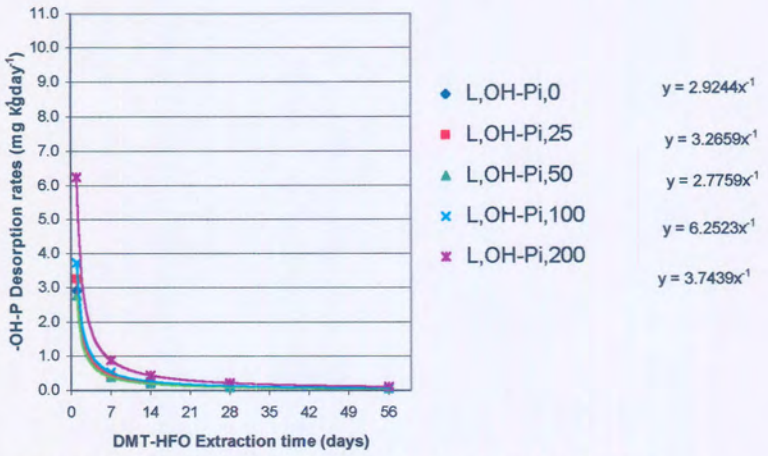

Fig. 9.2a. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

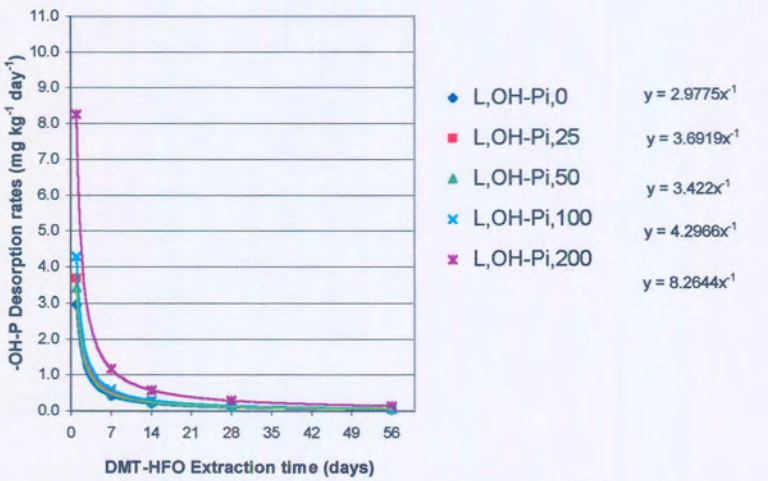

Fig. 9.2b. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

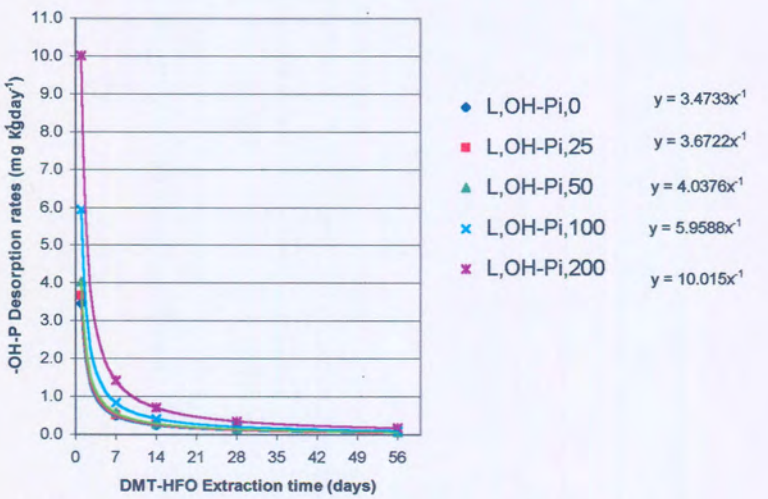

Fig. 9.2c. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

The contribution of –OH-P_i extracts to the total soil P pool between 1 and 56 days of successive DMT-HFO extractions increased from 16.44 and 12.94 % after (1 day) to 20.93 and 15.94 % after 240 days of incubation (Tables 4b-18b). These values are more or less the same as those obtained from the Rustenburg soil.

From the tables and graphs above it can be deduced that the amounts of –OH-P_i extracted, percent P recovered, P desorption rates, and contributions to the total soil P pool for both soils decreased with the successive DMT-HFO extractions, but increased with the increased days of incubation. The results further showed that higher amounts of –OH-P_i were extracted from Rustenburg soil throughout the incubation period, and that very high amounts of added P were extracted from the higher rates of applied P (100-200 mg kg^{-1}) on the first day of incubation from the Rustenburg soil (Tables 1-3; Figs. 7-8).

The differences between the two soils could also be due to the differences mainly in the soil clay content and types. The clay content especially the higher amounts of kaolinites could have contributed to the higher amounts of the P extracted and the relatively higher percent P recovered and desorption rates by the Rustenburg soil as more P was added through its higher adsorption capacity. According to Loganathan et al., (1987) this could have been as a result of the formation of P compounds associated with Fe- and Al- compounds which form at low to medium soil pH as was the case with both soils but relatively higher for the Rustenburg soil.

With the successive DMT-HFO extractions, the –OH-P_i showed highly significant decreases over the extraction time in both soils. It may therefore be deduced that NaOH-P_i, which showed the largest reductions in the soils inorganic P (P_i), was largely responsible for the replenishment of the labile-P pools. It should further be noted that the –OH-P_i concentration in Rustenburg soil was far higher than in the Loskop soil. This could help to prolong the supply of labile P over a longer period of time to the growing crops. It should also explain why labile-P_i as shown earlier decreased faster in Loskop soil than in Rustenburg soil. This is further supported by the P desorption rates where after 240 days of incubation and 56 days of extractions

Rustenburg still was able to release 0.15-0.21 as compared to 0.06-0.18 mg kg^{-1} day^{-1} of the Loskop soil.

–OH-P_o extracts:

For the Loskop soil both values for the –OH-P_o extracted after 1 day and 56 days of DMT-HFO extractions remained stable (9.20 and 7.11 to 15.13 and 15.93 mg kg^{-1}) (1 day) and (4.77 and 4.70 to 10.02 and 10.83 mg kg^{-1}) (56 days) for 0 and 200 mg kg^{-1} over the incubation period (Tables 1b-3b; Figs. 10a-c and 10.1a-c). These represented percent P recoveries of about 5-2 % (25-200 mg kg^{-1}) between 1 and 56 days of successive DMT-HFO extractions after 1-240 days of incubation (Figs. 10.1a-c).

The P desorption rates were also low and averaged about 0.8 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extraction and 0.02 mg kg^{-1} day^{-1} after 56 days of the successive DMT-HFO extractions (Figs. 10.2a-c). The contribution of –OH-P_o extracts to the total P pool also stood at about 5 % between 1 and 240 days of incubation following the successive DMT-HFO extractions (Tables 4b-18b).

Thus, the Loskop soil showed similar trends with the Rustenburg soil from the successive DMT-HFO extractions. The marginal changes noted could have been possibly due to more stable nature (in contrast to the –HCO_3-P_o) of this fraction of the soil organic matter, which was not very much affected by both the added inorganic P and the incubation times. There was thus, limited incorporation of the applied inorganic P into this organic P fraction by the soil microbes, and therefore, correspondingly limited contributions to the labile P pool in both soils (Figs. 10, 10.1 and 10.2; Tables 4 and 18). In a long-term field experiment, du Preez and Claassens (1999) found that the -OH-P_o made up 3.10-9.00 % and 4.60-8.60 % of the total soil P of Avalon and Clovelly soils after 12 and 14 years of long-term field trials respectively while Hedley et al. (1982) found -OH-P_i contributed about 15% of the total soil P from long-term wheat rotation trials.

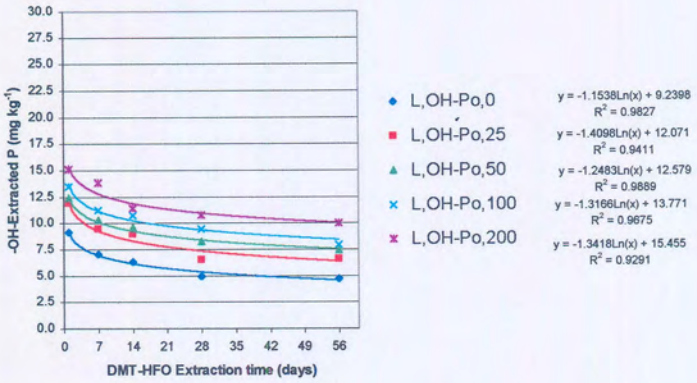

Fig. 10a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 1 day of incubation of Loskop soil

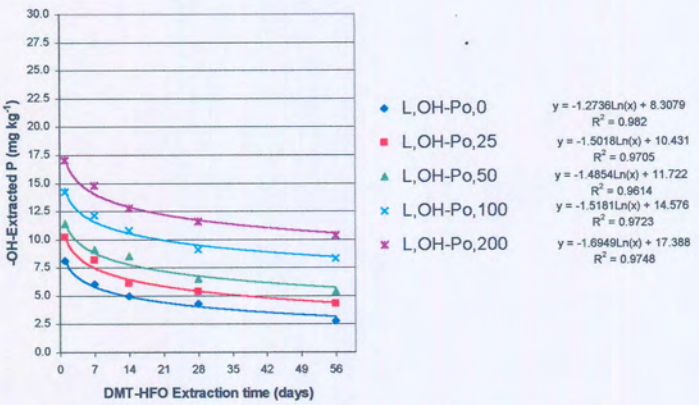

Fig. 10b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 120 days of incubation of Loskop soil

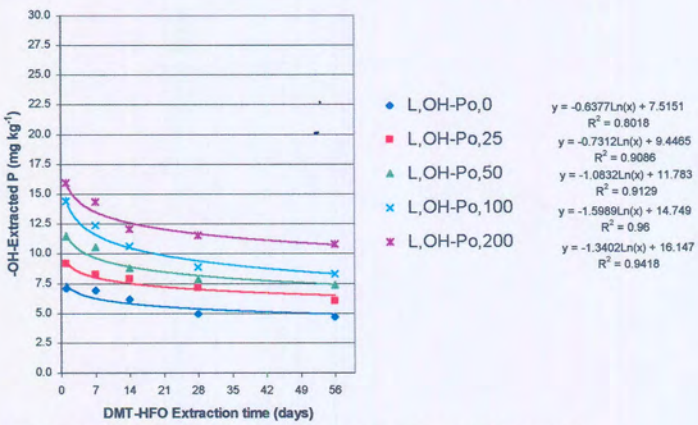

Fig. 10c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 240 days of incubation of Loskop soil

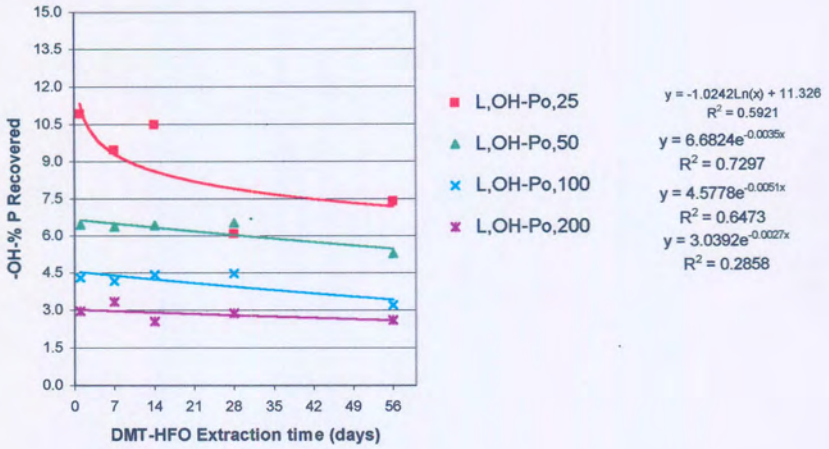

Fig.10.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 1 day of incubation of Loskop soil

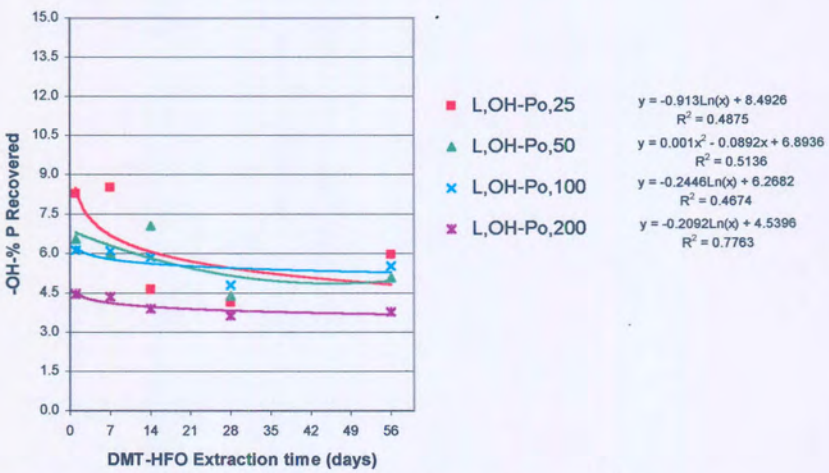

Fig.10.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 120 days of incubation of Loskop soil

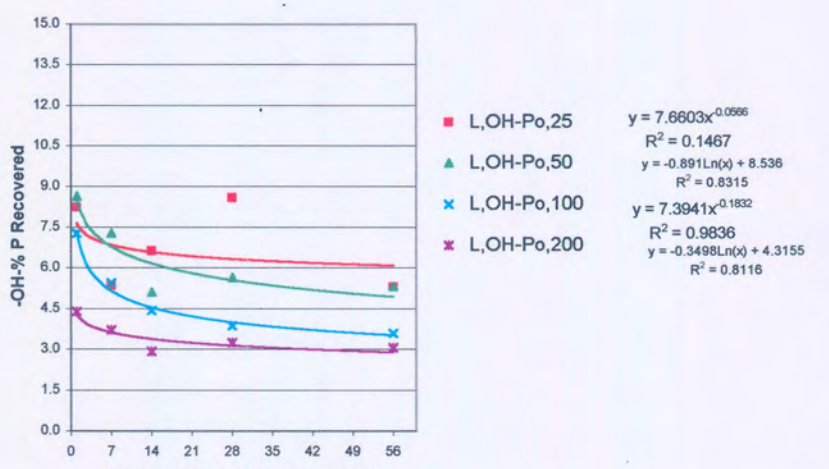

Fig.10.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 240 days of incubation of Loskop soil

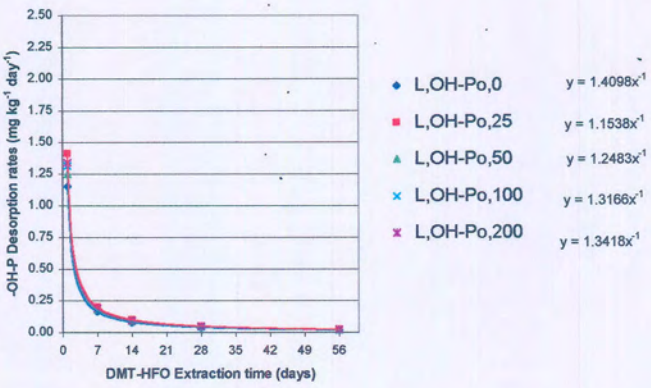

Fig. 10.2a. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

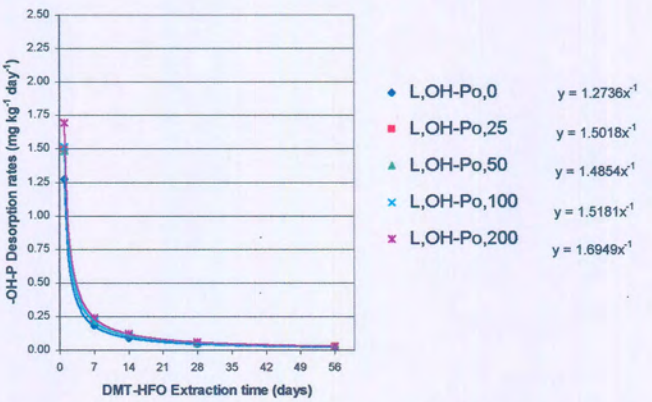

Fig. 10.2b. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

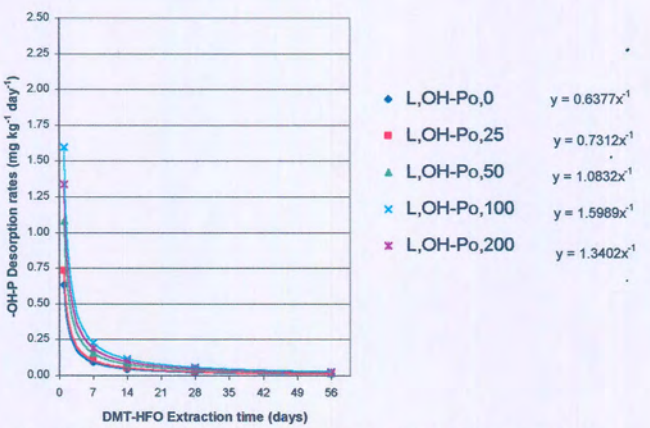

Fig. 10.2c. The effects of the added P and DMT-HFO extractions on -OH-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

2c: (ii). The changes in the distribution of the 1M HCl-extractable P pool (D/HCl- P_i) after successive (DMT-HFO) extractions

2c: (ii). (a). Rustenburg soil

The amounts of the D/HCl-P_i extracted between 1 and 56 days of the successive DMT-HFO extractions remained relatively low and stable over the incubation period. They varied from 8.43 and 5.00 to 20.62 and 13.23 mg kg^{-1} after 1 day of incubation and from 9.87 and 5.40 to 27.53 and 14.30 mg kg^{-1} (240 days) between the lowest and highest levels of applied P respectively (Tables 1a-3a; Figs. 11a-c). The percent P recoveries of the D/HCl-P_i after 1-56 days of the successive DMT-HFO extractions were generally low (below 10 %) between 25 and 200 mg kg^{-1} applied P from most of the applied P levels (Tables 1a-3a; Figs. 11.1a-c).

The desorption rates of the D/HCl-P_i between 1 and 56 days of the successive DMT-HFO extractions were also generally low. They changed from 1.09 and 1.11 to 1.90-3.26 mg kg^{-1} day^{-1} after 1 day of extraction and from 0.01 and 0.02 to 0.03 and 0.06 mg kg^{-1} day^{-1} after 56 days of extractions from the lowest and highest levels of applied P respectively (Figs. 11.2a-c). The contributions of D/HCl-P_i extracts to the total soil P pool were also low at about 5 % between 1 and 56 days of successive DMT-HFO extractions (Tables 4a-18a).

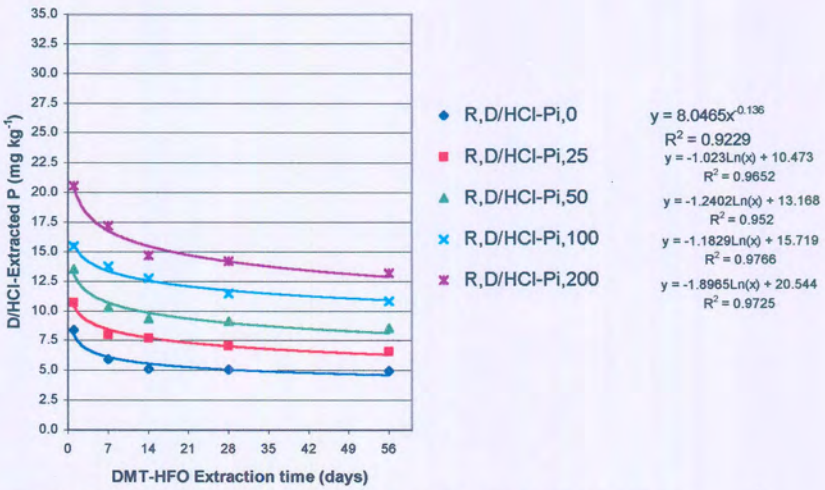

Fig. 11a. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 1 day of incubations of Rustenburg soil

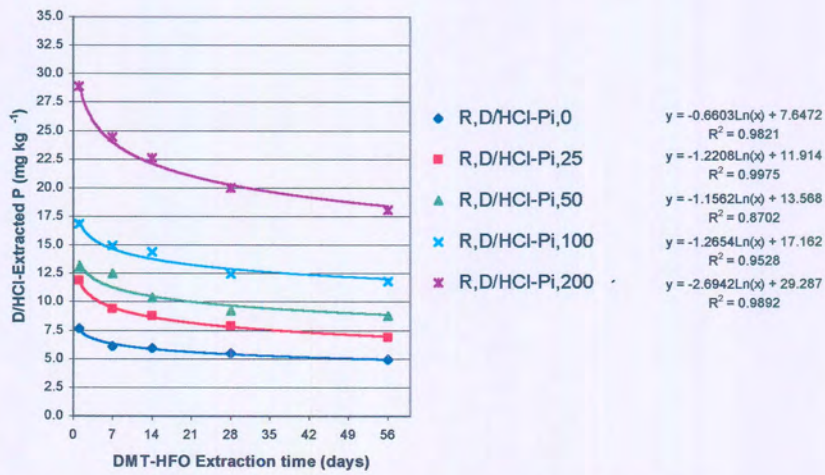

Fig. 11b. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 120 days of incubations of Rustenburg soil

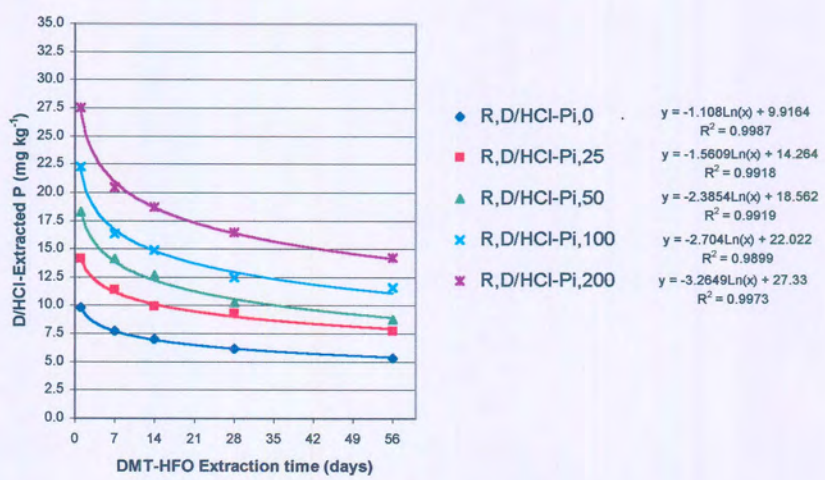

Fig. 11c. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 240 days of incubation of Rustenburg soil

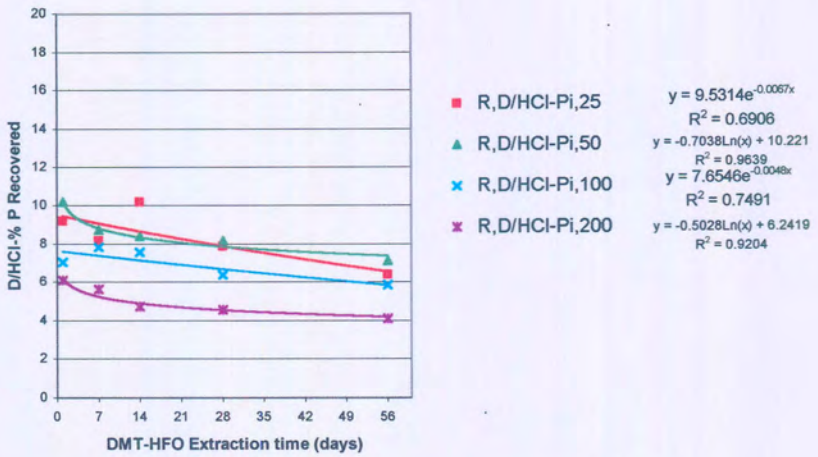

Fig. 11.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 1 day of incubation of Rustenburg soil

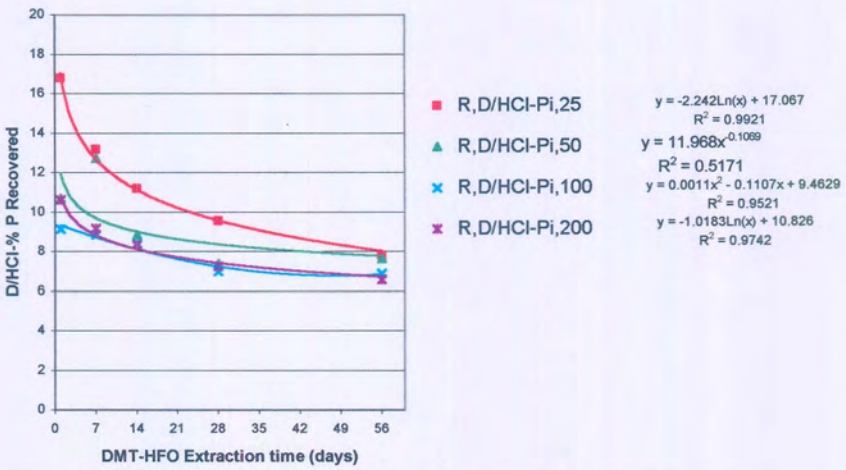

Fig. 11.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 120 days of incubation of Rustenburg soil

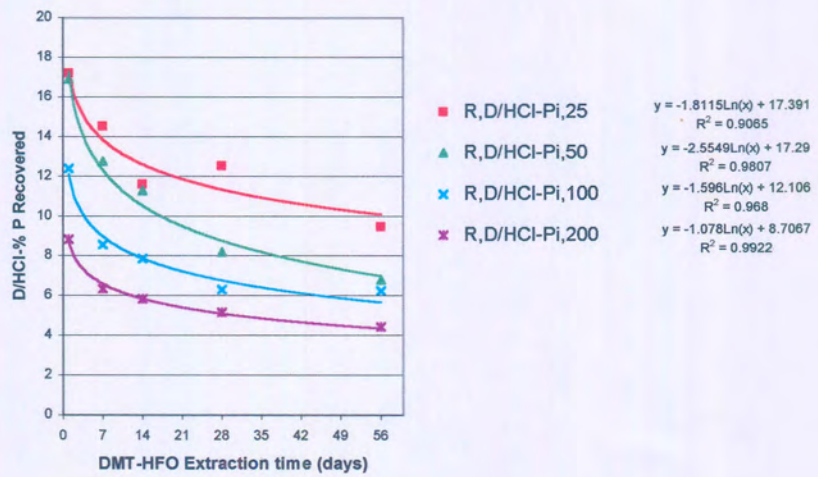

Fig. 11.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 240 days of incubation of Rustenburg soil

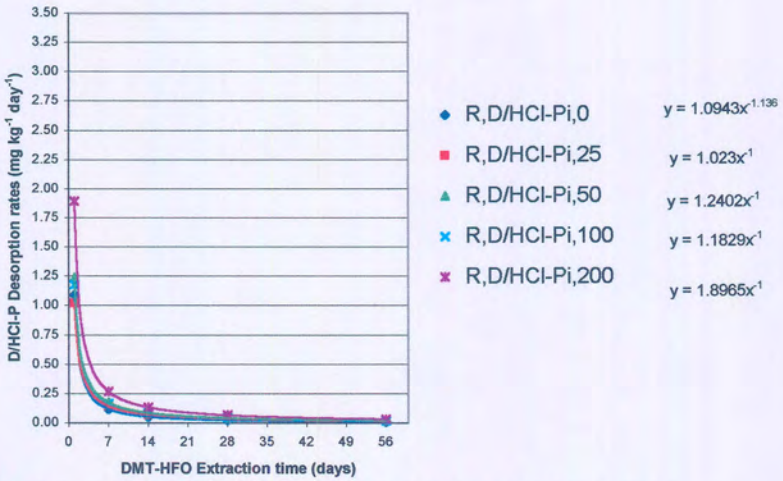

Fig. 11.2a. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

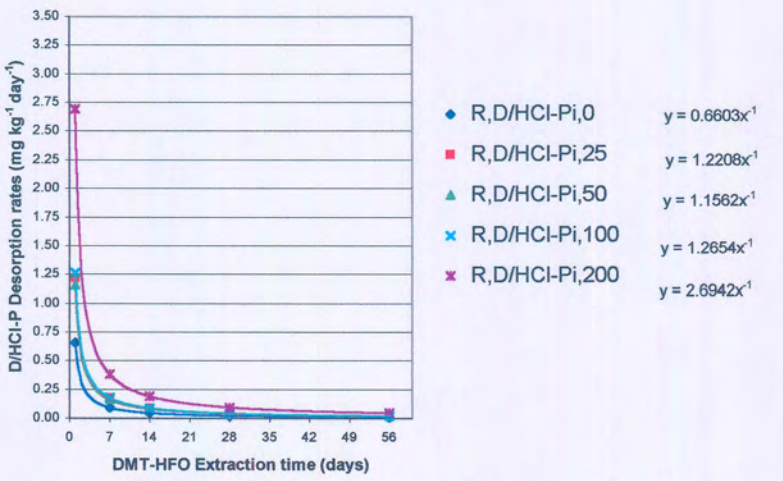

Fig. 11.2b. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubations of Rustenburg soil

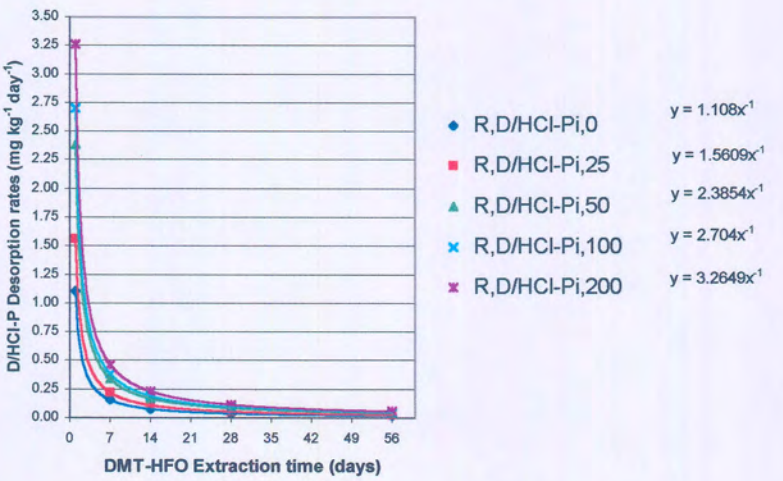

Fig. 11.2c. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

2c: (ii). (b). Loskop soil

With the Loskop soil, the corresponding values for the D/HCl-P_i extracted after 1-56 days of successive DMT-HFO extractions were even lower, ranging from 6.13 and 4.30 to 14.07 and 9.10 mg kg^{-1} after 1 day of incubation and from 6.65 and 5.30 to 19.40 and 12.73 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} added P respectively (Tables 1b-3b; Figs.12a-c).

The percent P recoveries after 1 - 56 days of successive DMT-HFO extractions were also lower than those of the Rustenburg soil. They were reduced from 7.08 and 2.52 to 3.97 and 2.40 % after 1 day of incubation and from 9.92 and 4.00 to 6.38 and 3.72 % (240 days) between 25 and 200 mg kg^{-1} (Tables 1b-3b; Figs. 12.1a-c).

Further, the desorption rates between 1 and 56 days of successive DMT-HFO extractions were also lower than those of the Rustenburg soil. They varied from 0.45 and 0.36 to 1.29 and 1.72 mg kg^{-1} day^{-1} after 1 day of incubation and remained relatively unchanged from 0.01 to 0.02 and 0.03 mg kg^{-1} day^{-1} after 240 days of incubation between 25 and 200 mg kg^{-1} respectively (Figs. 12.2a-c). The contributions of the D/HCl-P_i extracts to the total soil P pool were also low in most cases below 5 % over the incubation period (Tables 4b-18b).

It is therefore noted here that the D/HCl-P_i extracts and the percent P recoveries followed similar trends as those of the -OH-P_i in both soils. The only differences were in the amounts of the extracts. The changes with Rustenburg soil were relatively larger, reflecting a greater contribution to the labile P pool. However, in general the HCl-P_i fraction contributed relatively smaller percentage to the total soil P pool (Tables 4a, b-18a, b). The changes with the extraction times were thus small, indicating that this fraction was of limited importance in replenishments of the labile P pool, especially with the Loskop soil. According to du Preez and Claassens (1999) this fraction contributed less than 1% of the total soil P pool in the Clovelly soil. While Sattell and Morris (1992) found 8 % contribution to the total soil P pool in

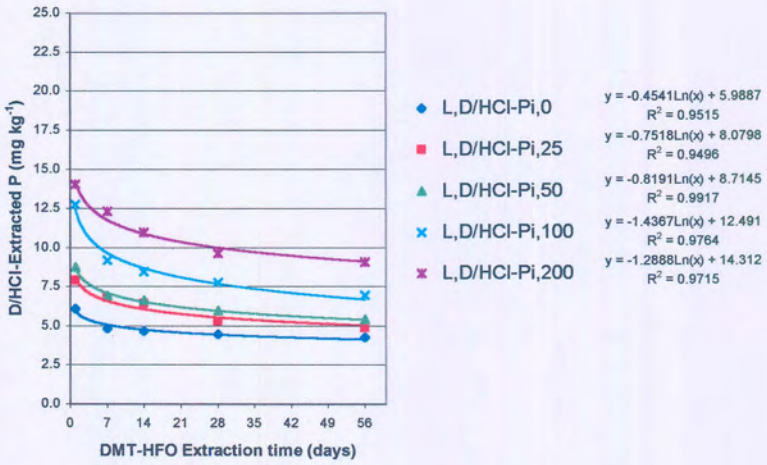

Fig. 12a. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 1 day of incubation of Loskop soil

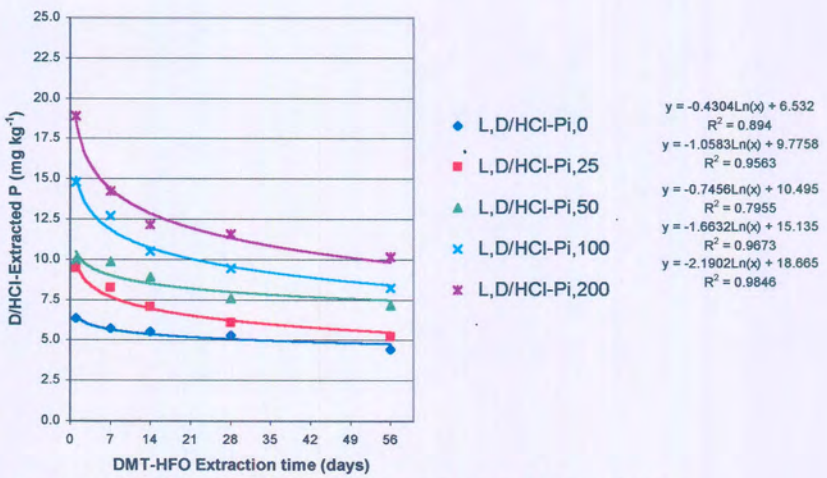

Fig. 12b. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 120 days of incubation of Loskop soil

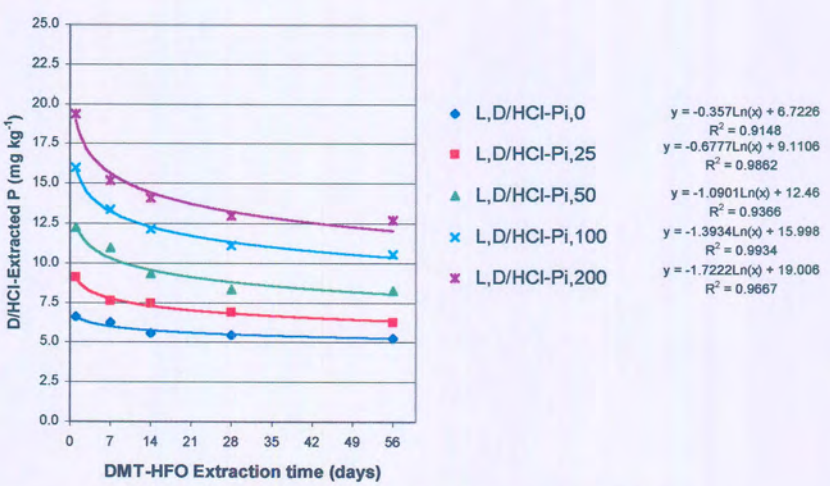

Fig. 12c. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 240 days of incubation of Loskop soil

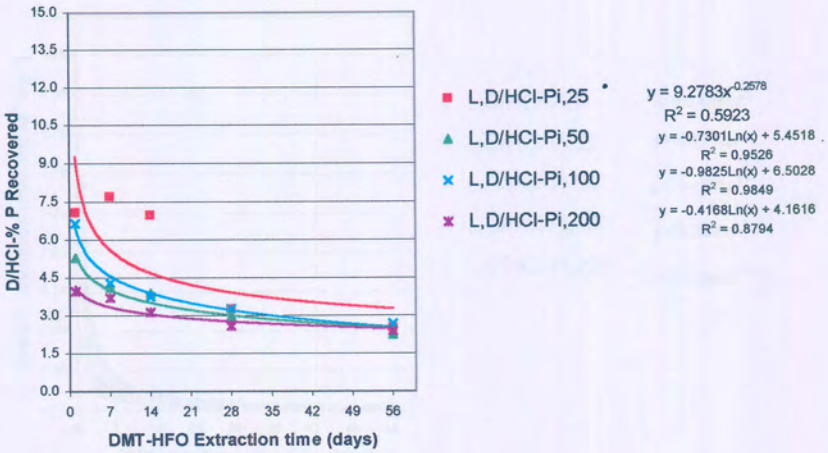

Fig. 12.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 1 day of incubation of Loskop soil

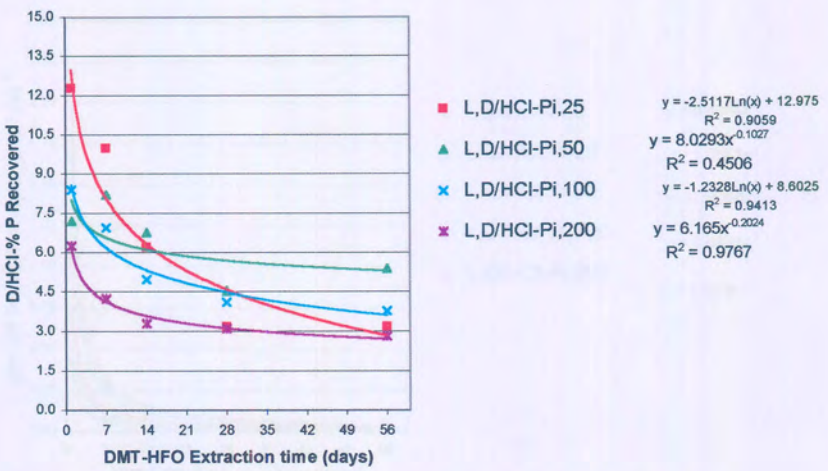

Fig. 12.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 120 days of incubation of Loskop soil

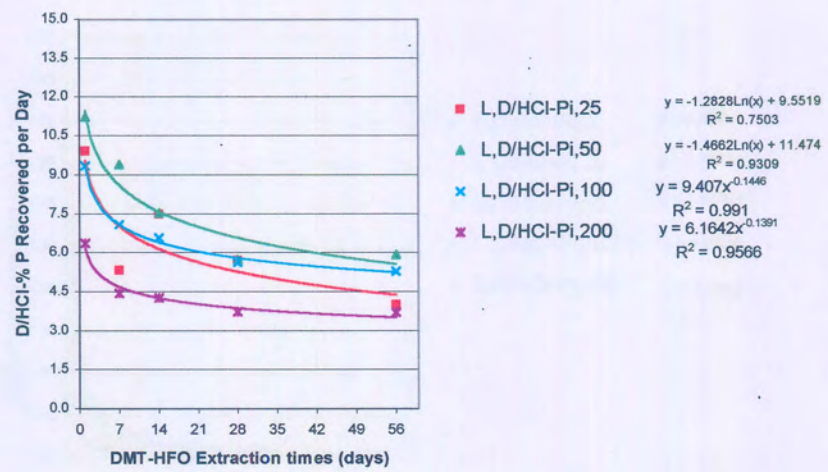

Fig. 12.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 240 days of incubation of Loskop soil

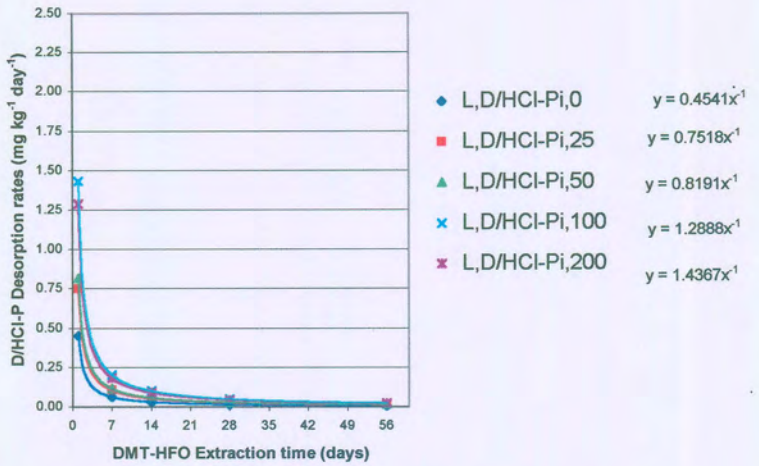

Fig. 12.2a. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

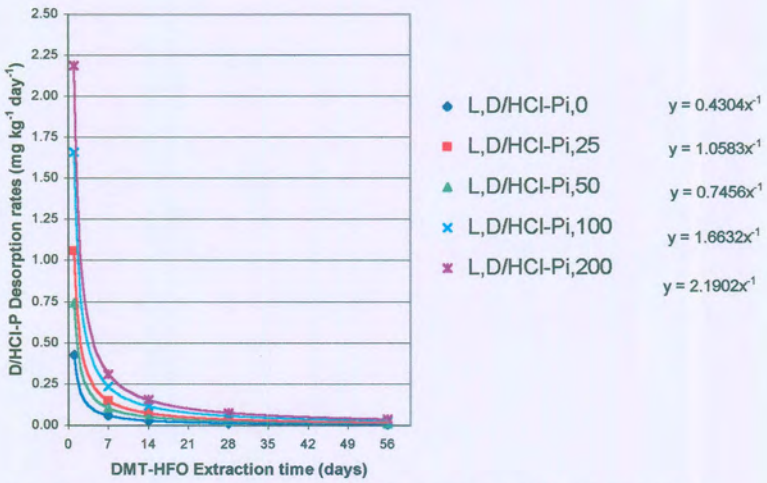

Fig. 12.2b. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

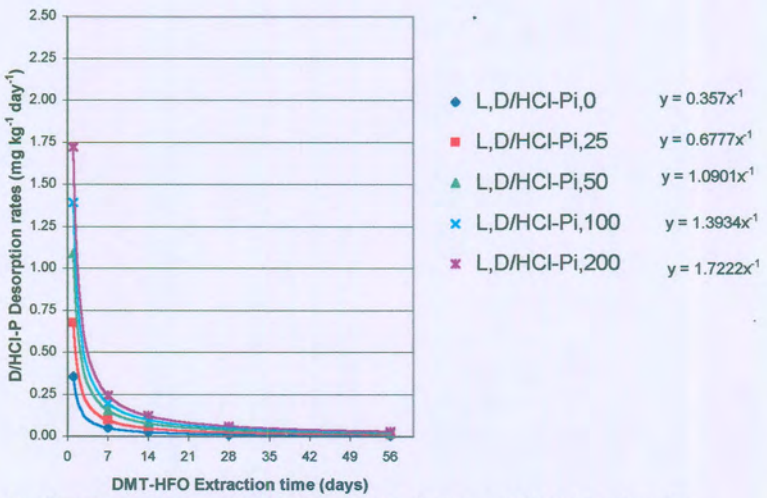

Fig. 12.2c. The effects of the added P and DMT-HFO extractions on D/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

average and Hedley, et al., (1982) found this pool contributed an average of 7 % to the total extracted soil P pool.

Total slow or moderately labile P_i pool (0.1M NaOH-P_i and 1.0M HCl-P_i extracts)

The slow or moderately labile P_i (–OH-P_i and D/HCl-P_i) fraction accounted for the largest proportion of the soil P_i in the Rustenburg but the second largest in Loskop soil, where labile P_i (DMT-HFO + -HCO_3-P_i) was the largest at the start of the extractions. Rustenburg had 24.51 and 30.56 %, while Loskop had 21.01 and 26.78 % of the total soil P pool, between 1 and 240 days of incubation respectively (Tables 7a-b and 17a-b). Work by du Preez and Claassens (1999) with Avalon and Clovelly soils showed that this pool also accounted for the largest proportion of the P_i, with 12.9-17.0 % and 15.8-12.8 % of the total soil P pool for Avalon and Clovelly respectively.

The values of the slow or moderately labile P_i fraction showed that incubation period resulted in increases of between 64.06–90.23 (26.17) mg kg^{-1} between 1 and 240 days for Rustenburg soil, and corresponding values for Loskop soil ranged between 47.60 and 63.08 (15.48) mg kg^{-1} (Tables 4 and 18). Increases in the moderately available plant P noted in the two soils could have been the results of the formations of P associated with Fe-, Al-, Ca-, and Mg- compounds, which form at low to medium soil pH as was the case of both soils (Loganathan et al., 1987).

2d: The effects of the added P, incubation time, and successive DMT-HFO extractions on the insoluble P pool (conc. HCl-extractable P "C/HCl-P_i and P_o" conc. H_2SO_4 + H_2O_2-extractable P "H_2SO_4-P_i").

2d: (i). Changes in the distribution of conc. HCl-extractable P pool (C/HCl-P_i and P_o) after successive DMT-HFO extractions

2d: (i). (a). Rustenburg soil

Conc. HCl-extracted P_i

The changes and distribution of conc. HCl-extractable P_i (C/HCl-P_i) after the successive DMT-HFO extractions shown in Tables 1a-3a, Figures 13, 13.1 and 13.2 were highly significant (P = 0.01 %) (Appendices II No. 5).

The amounts of the C/HCl-P_i extracted from the Rustenburg soil increased from 48.33 and 54.67 to 58.70 and 95.80 mg kg^{-1} (0-200 mg kg^{-1} added P) between 1 and 56 days of the successive DMT-HFO extractions and 35.77 and 49.87 to 38.27 and 71.67 mg kg^{-1} (0-200 mg kg^{-1}) after 240 days of incubation (Tables 1a-3a; Figs. 13a-c). These represented percent P recovery of about 5 % of the C/HCl-P_i after 1 day of incubation. However, the percent P recovered after 240 days of incubation varied from about 10 % to 15 % between the lowest and highest applied P levels (Tables 1a-3a; Figs. 13.1a-c).

They also represented P desorption rates of about 3.00-5.00 mg kg^{-1} day^{-1} of the C/HCl-P_i after 1 day of the DMT-HFO extractions between the lowest and highest added P levels. However, the P desorption rates after 56 days of the successive extractions reduced significantly to about 0.01-0.1 0 mg kg^{-1} day^{-1} between the lowest and highest added P levels respectively (Figs. 13.2a-c). In contrast the contributions of C/HCl-P_i extracts to the total soil P pool were high and ranged from 20-25 % between 1 and 240 days of incubation (Tables 4a-18a).

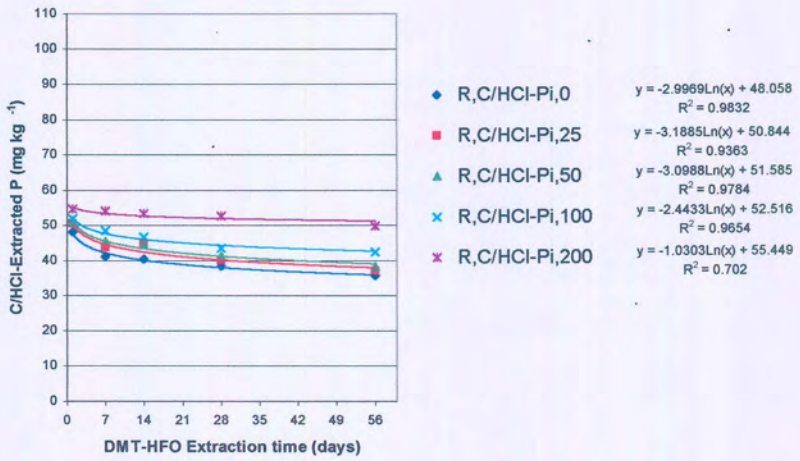

Fig. 13a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 1 day of incubation of Rustenburg soil

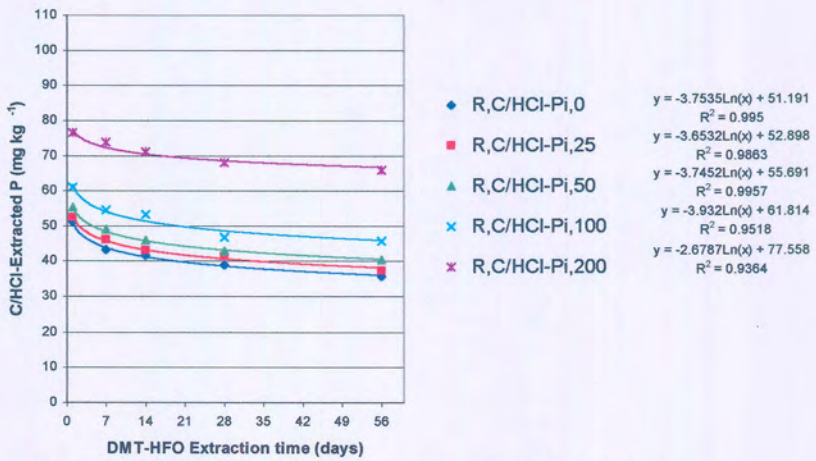

Fig. 13b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 120 days of incubation of Rustenburg soil

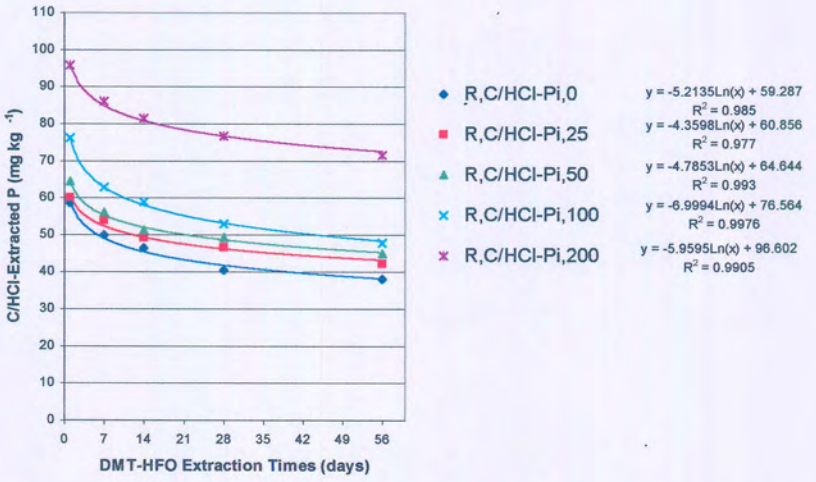

Fig. 13c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 240 days of incubation of Rustenburg soil

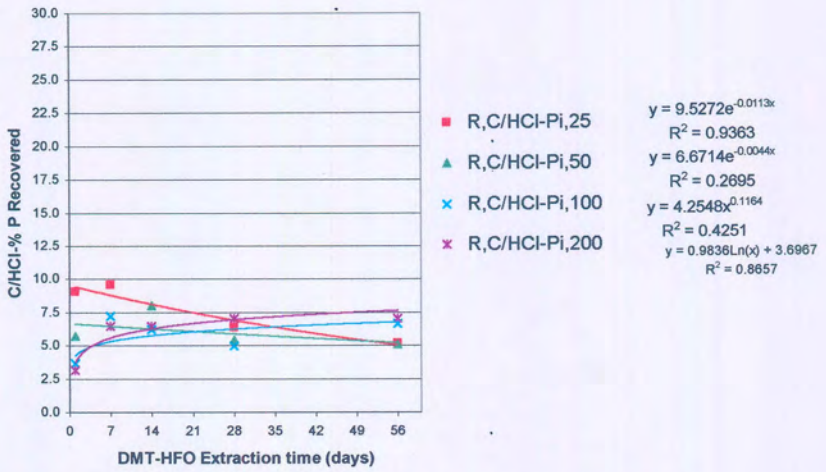

Fig. 13.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 1 day of incubation of Rustenburg soil

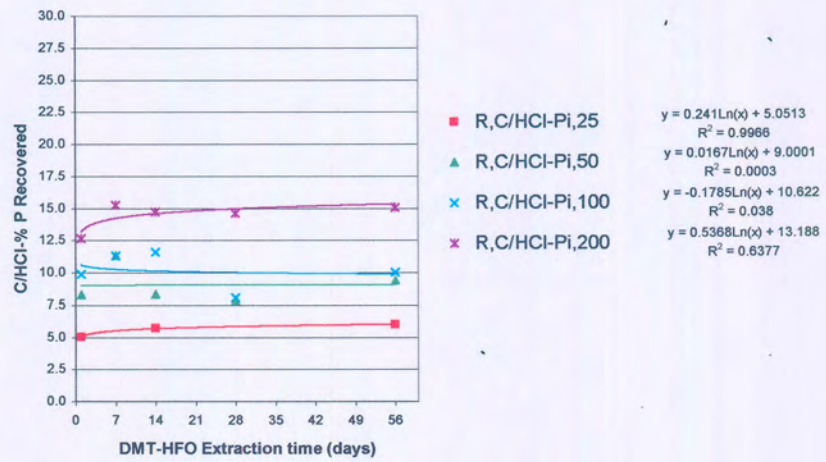

Fig. 13.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 120 days of incubation of Rustenburg soil

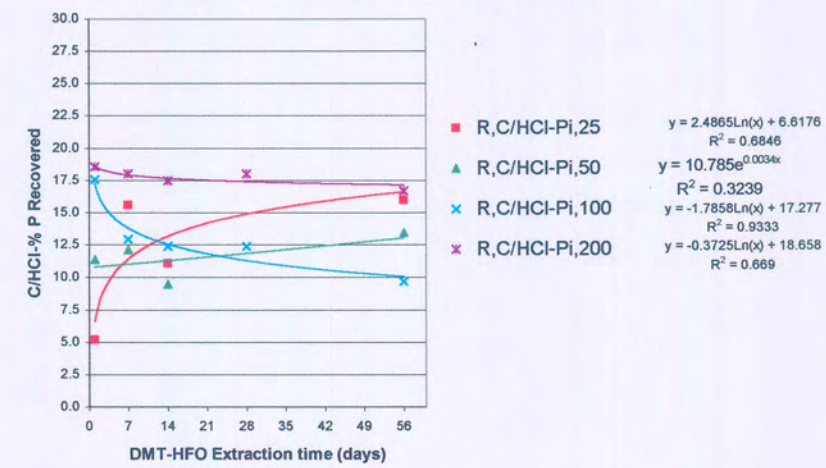

Fig. 13.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 240 days of incubation of Rustenburg soil

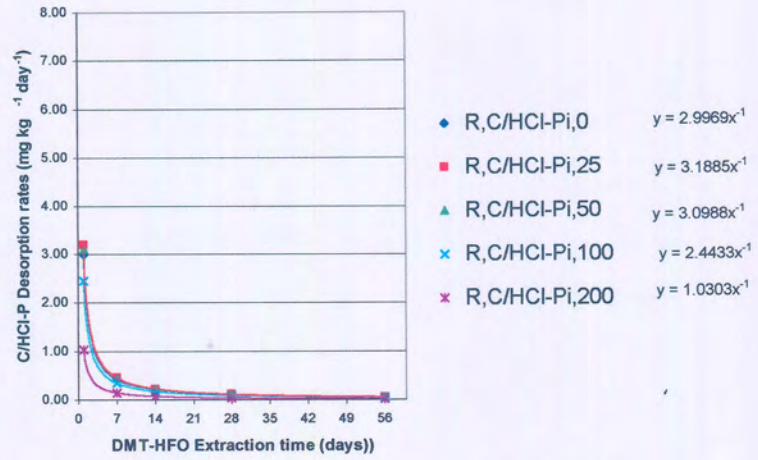

Fig. 13.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

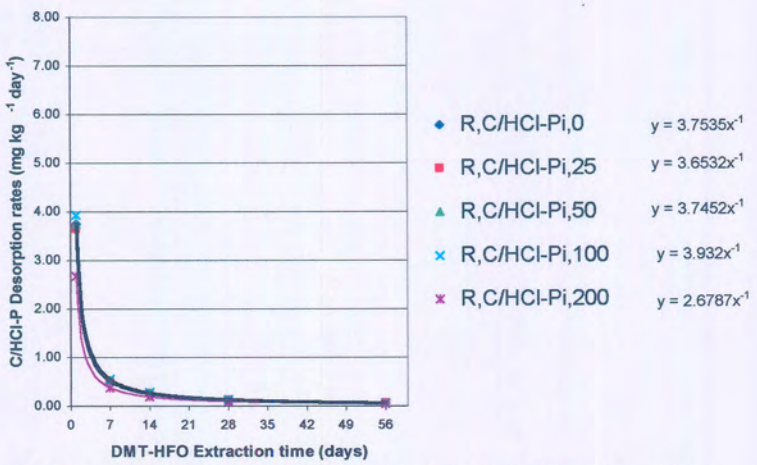

Fig. 13.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

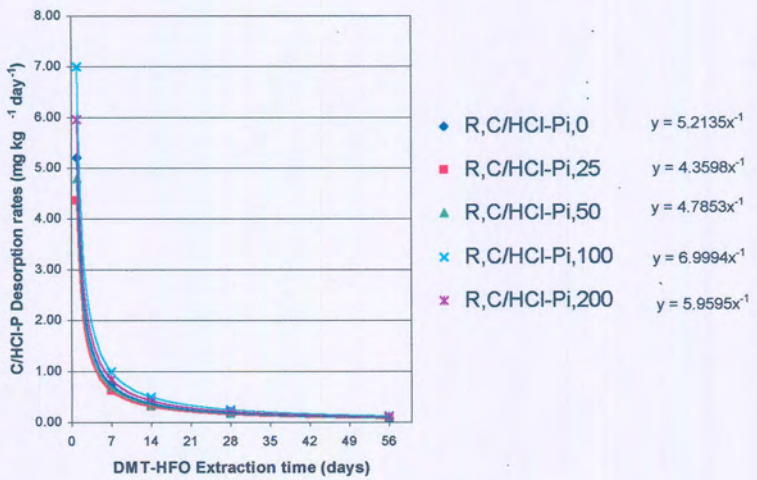

Fig. 13.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

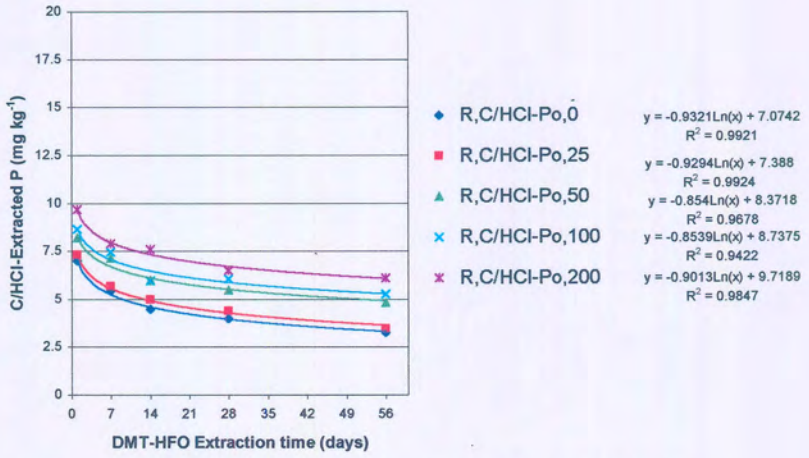

Fig. 14a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 1 day days of incubation of Rustenburg soil

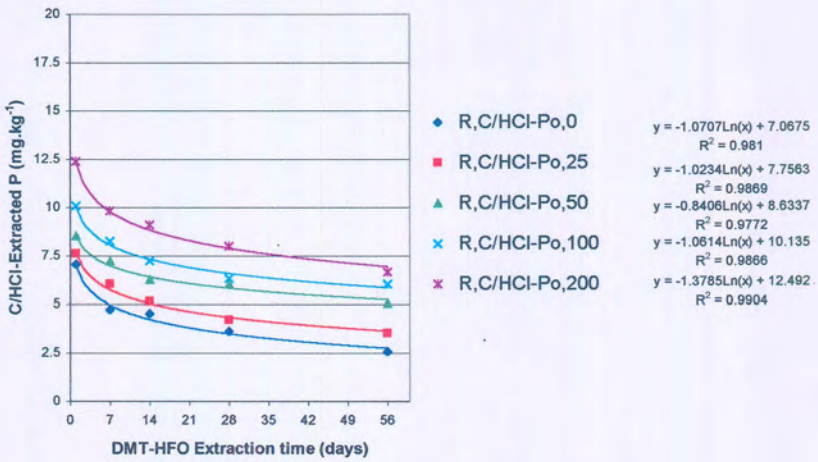

Fig. 14b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 120 days of incubation of Rustenburg soil

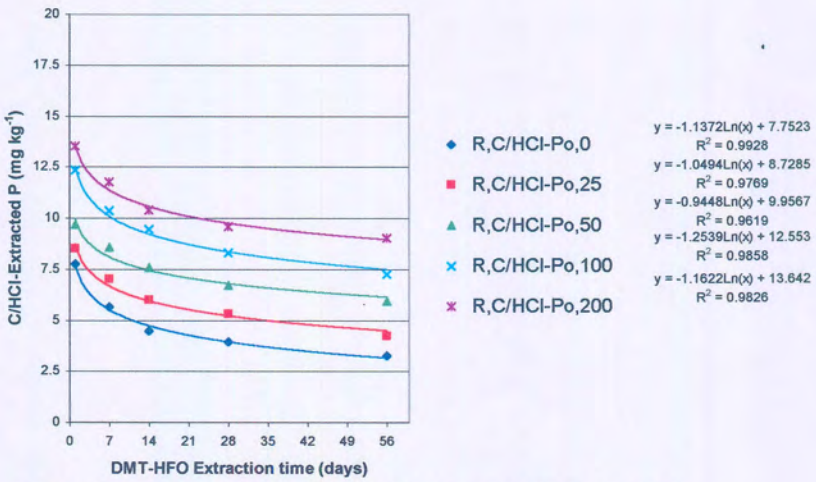

Fig. 14c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 240 days of incubation of Rustenburg soil

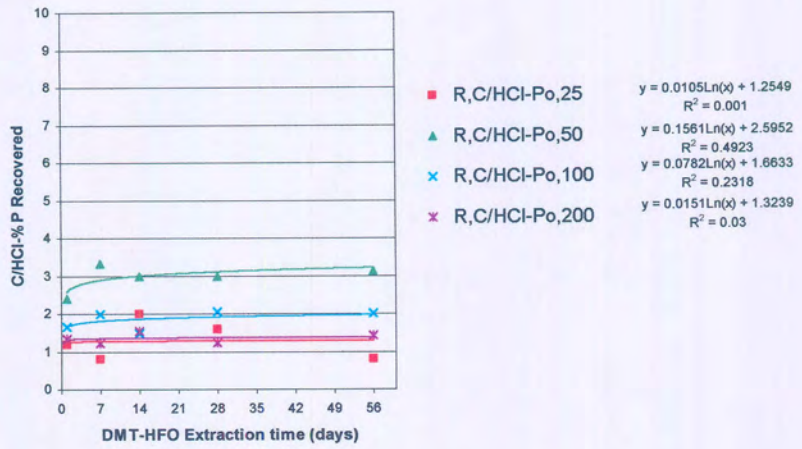

Fig. 14.1a.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 1 day of incubation of Rustenburg soil

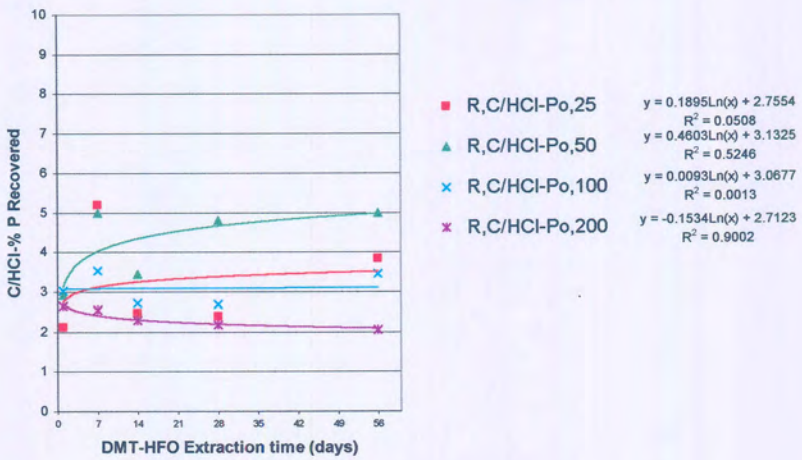

Fig. 14.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 120 days of incubation of Rustenburg soil

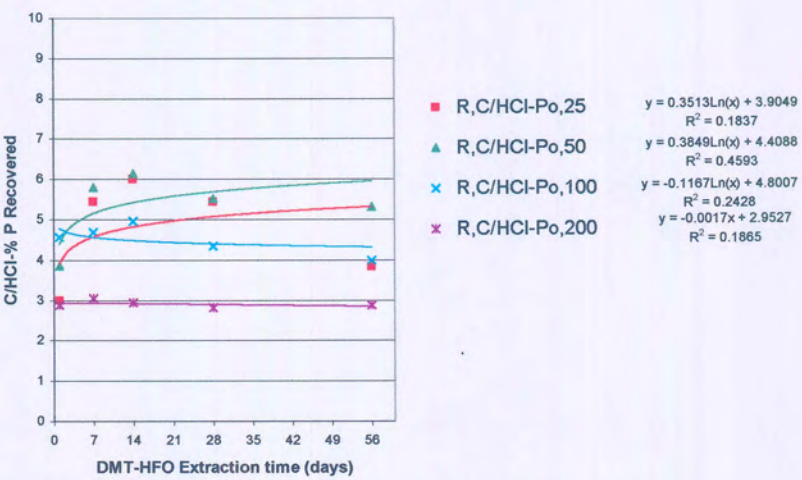

Fig. 14.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 240 days of incubation of Rustenburg soil

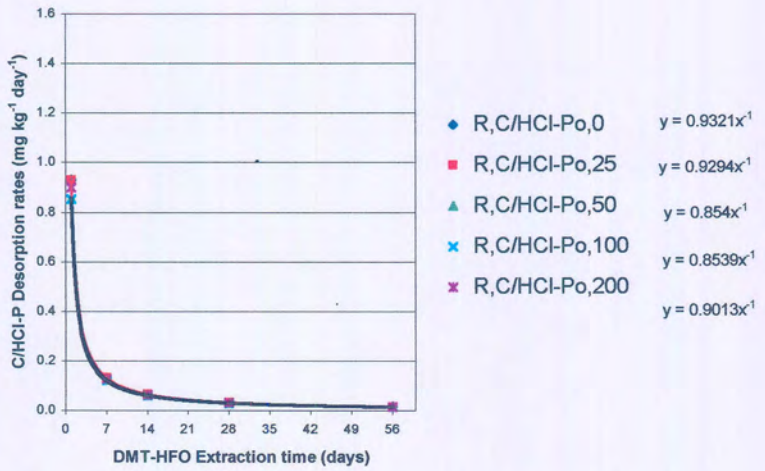

Fig. 14.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubations of Rustenburg soil

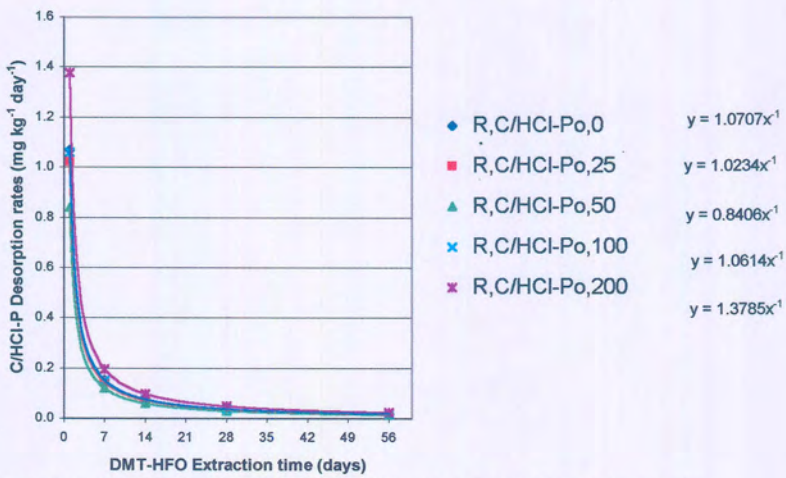

Fig. 14.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

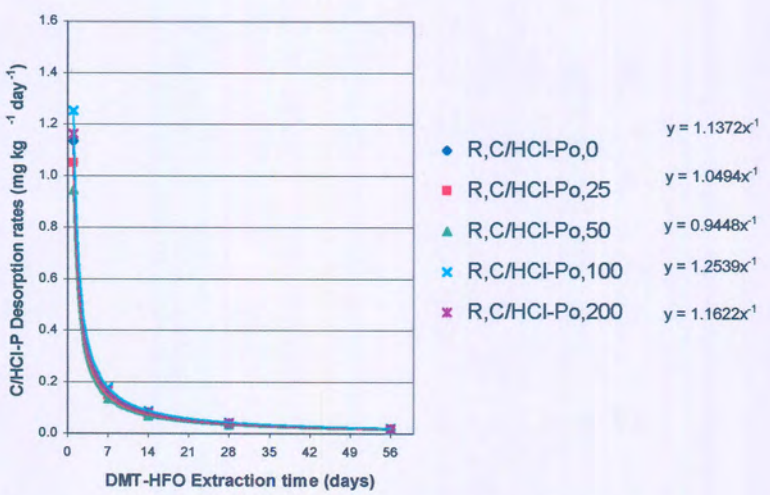

Fig. 14.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

C/HCl-P_o extracts

The conc. HCl-P_o extracts (C/HCl-P_o) after the successive DMT-HFO extractions shown in Tables 1a-3a, and Figures 14a-c, 14.1a-c, and 14.2a-c were also highly significant (Appendices II No. 9). The amounts of P extracted with each successive DMT-HFO extractions between 1 and 56 days remained nearly constant at about 3-7 mg kg^{-1} from the lowest to the highest applied P (Tables 1a-3a; Figs. 14a-c). The incubation period before the extraction did not have much effect. According to Figs. 15a-c and 15.1a-c there were slight decreases between 1-28 days of extractions where after no significant changes were apparent between 28-56 days of extraction at all levels of added P and the incubation periods. These amounts represented a very low percent P recovery of about 1 % after 1 day of incubation. The percent P recovery increased slightly to about 3 % after 240 days of incubation (Tables 1a-3a; Figs. 14.1a-c).

The P desorption rates were also marginal, averaging about 1.0 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions and 0.02 mg kg^{-1} day^{-1} after 56 days of the successive DMT-HFO extractions (Figs. 14.2a-c). The contributions of C/HCl-P_o extracts to the total soil P pool were also low at an average of 3 % between 1 and 240 days of incubation (Tables 4a-18a).

2d: (i). (b). Loskop soil

C/HCl-extracted P_i:

The corresponding values for the C/HCl-P_i extracted varied from 31.10 and 25.87 to 40.53 and 34.77 mg kg^{-1} after 1 day of incubation and from 38.00 and 27.27 to 59.27 and 50.33 mg kg^{-1} after 240 days of incubation between 0 and 200 mg kg^{-1} added P (Tables 1b-3b; Figs. 15a-c). These values were much lower than the values for the Rustenburg soil.

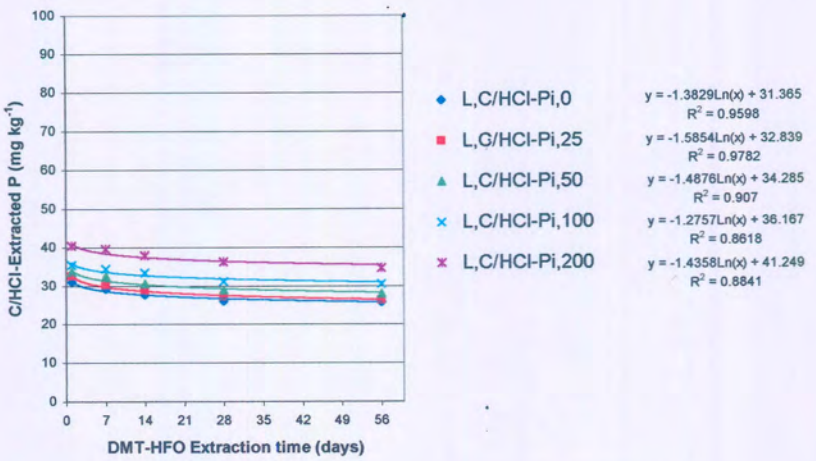

Fig. 15a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 1 day of incubation of Loskop soil

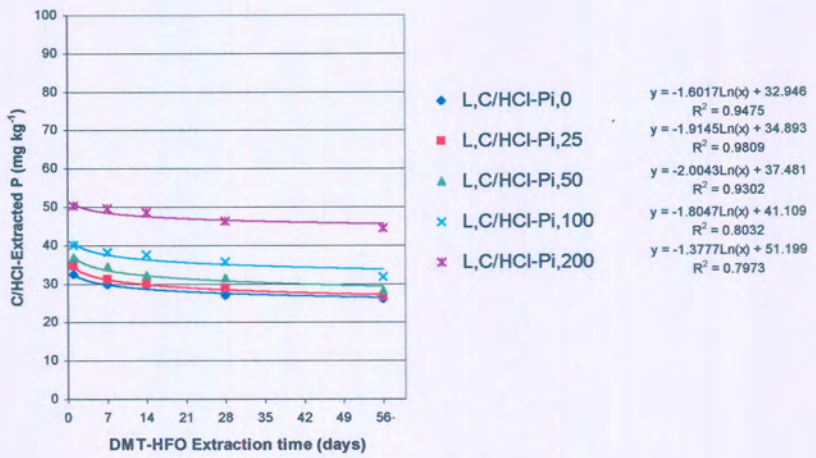

Fig. 15b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 120 days of incubation of Loskop soil

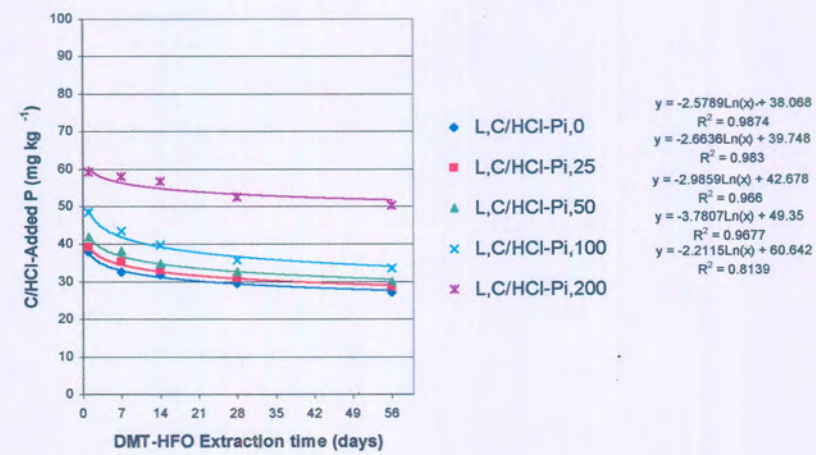

Fig. 15c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 240 days of incubation of Loskop soil

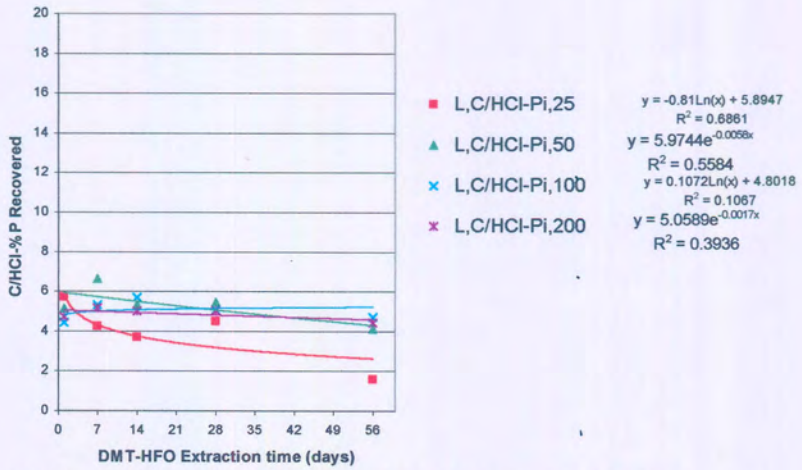

Fig. 15.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 1 day of incubation of Loskop soil

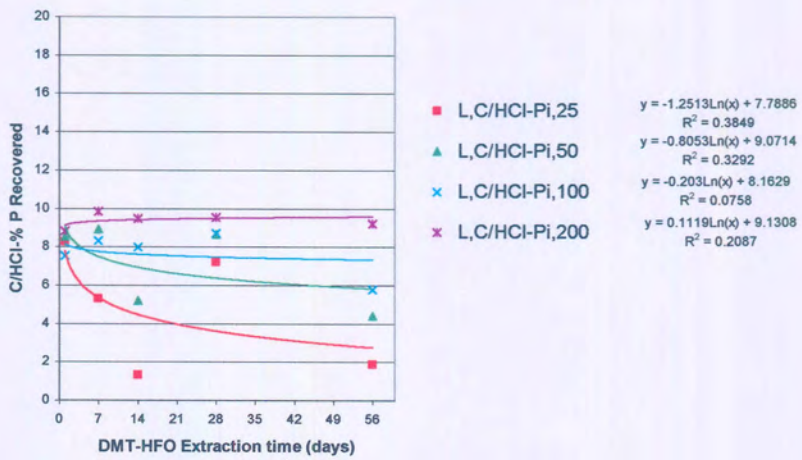

Fig. 15.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 120 days of incubation of Loskop soil

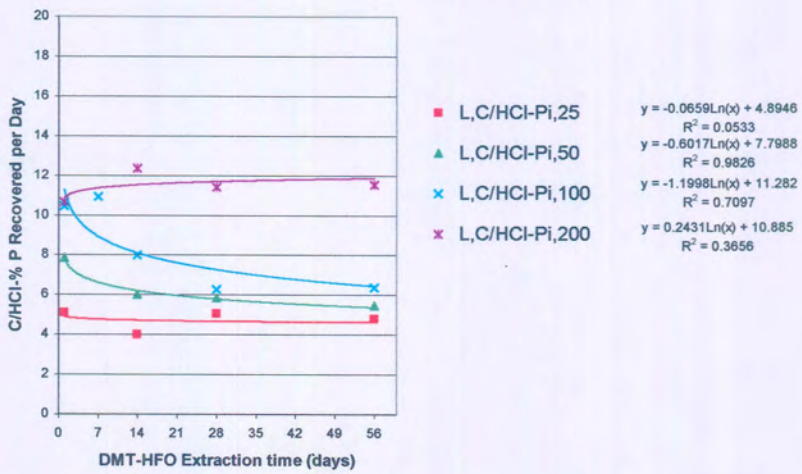

Fig. 15.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 240 days of incubation of Loskop soil

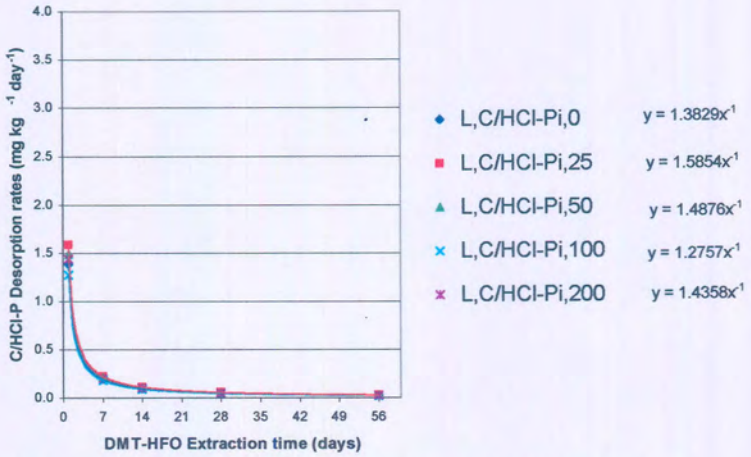

Fig. 15.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

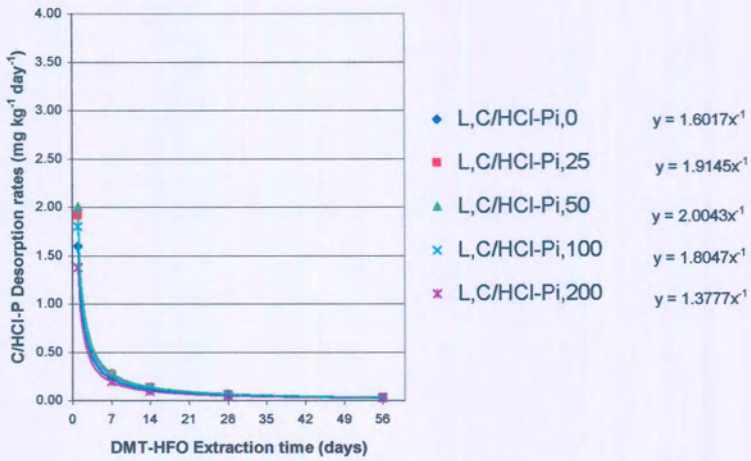

Fig. 15.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

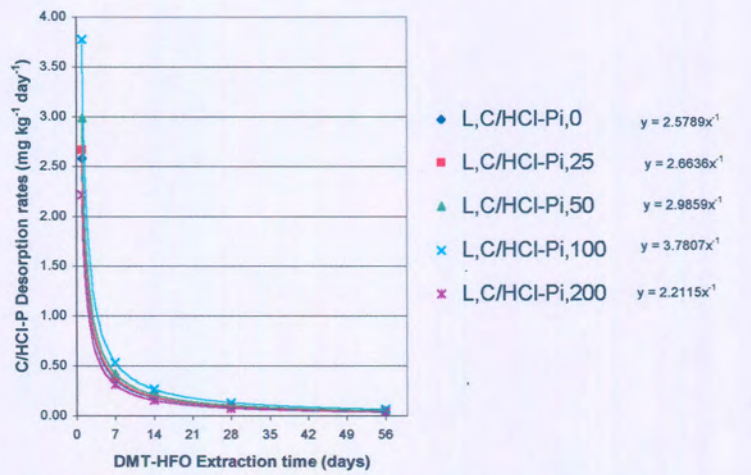

Fig. 15.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

Figures 15a-c and 15.1a-c also show similar reductions as was for the Rustenburg soil, where the highest P application rate (200 mg kg^{-1}) gave almost straight-line response curve. The fact that for the highest application rate (200 mg kg^{-1}) relatively more P was extracted compared to the other application rates indicated that this pool became saturated and that more P could still be extracted from this pool. However, compared to Rustenburg soil, relatively smaller amounts of C/HCl-P_i were extracted. This agrees with Bramley and Barrow (1992) who indicated that at low P concentrations, available and easily reached P sorption sites are occupied first, while at higher P concentrations, the more difficult sorption sites are also occupied but the P amounts adsorbed on those sites are smaller.

The percentage recoveries from the added P between 1 and 56 days of the successive DMT-HFO extractions were low (1-5 %) after 1 day of incubation and from 5-10 % after 240 days of incubation with 25 and 200 mg kg^{-1} applied P (Tables 1b-3b; Figs. 15.1a-c). The P desorption rates between 1 and 56 days of the successive DMT-HFO extractions were lower than of the Rustenburg soil. The rates reduced from 1.5 and 2.5 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions to 0.02 and 0.05 mg kg^{-1} day^{-1} after 56 days of extractions between 0 and 200 mg kg^{-1} applied P (Figs. 15.2a-c). The contribution to the total soil P pool was also lower than of the Rustenburg soil at about 15-20 % between 1 and 240 days of incubation (Tables 4b-18b).

These findings also tended to agree with those of du Preez and Claassens (1999) with the Clovelly soil where the ultra-sonicated hydroxide P_i (NaOH-II-P_i) (roughly equivalent to conc. HCl-P_i extract, of Tiessen and Moir, 1993), in long-term field trials remained unchanged between about 45.3-51.5 mg kg^{-1}. However, the extracts for Avalon, which decreased with time, were very low (19.30-7.55 mg kg^{-1}). However, Tiessen and Moir (1993) found values of 193 mg kg^{-1} conc. HCl-P_i extract for Chernozem (mollisol) from native prairie, and 140 mg kg^{-1} from similar soil after 65 years cultivation in Canada.

However the fact that the conc. HCl-P_i in both soils decreased with the extraction time suggests that the conc. HCl-P_i contributed to the labile P pool over the period of

extraction time. However, the contributions were relatively small compared to the amounts extracted and the proportion of the total soil P pool they occupy.

C/HCl-extracted P_o:

The corresponding values of the C/HCl-P_o extracts for Loskop soil was equally low and did not change much (average 5 mg kg^{-1}) over the days of successive DMT-HFO extractions after 1 day of incubation and did not change much between the lowest and highest P levels. The extracts after 240 days of incubation were slightly higher (average 8 mg kg^{-1}) (Tables 1b-3b; Figs. 16a-c). Figures 16a-c and 16.1a-c also show marginal reductions with the successive extractions and increasing incubation times just like for the Rustenburg soil, but only a bit lower. As it has been stated earlier, the marginal changes recorded could have been due to the more stable nature of this fraction of the soil organic matter, which was not so much affected by both the incubation period and the added inorganic P (Oades and Ladd, 1977; Hedley et al., 1982; Sattell and Morris, 1992). However, the noted reductions of the conc. HCl-P_o in both soils following the successive extractions, although marginal would suggest that the conc. HCl-P_o contributed to the labile P pool.

These values represented very low percent P recovery (3-1 %) from the added P between 1 and 56 days of successive DMT-HFO extractions on 1 day incubated soil and an average of 3 % after 240 days of incubation. The P desorption rates were accordingly very low, averaging about 1.0 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions and 0.02 mg kg^{-1} day^{-1} after 56 days of the successive DMT-HFO extractions (Figs. 16.2a-c). The contribution to the total soil P pool was equally very low and relatively constant at 2-4 % and little affected by incubation time and successive DMT-HFO extractions (Tables 4b-18b).

The extracted C/HCl-P_o as fractions of the total P pool were similar to the findings by du Preez and Claassens (1999) who reported 6.4-8.5% and 1.6-3.4% from Avalon and Clovelly soils respectively. Hedley et al., (1982) had reported that P_o extracted in the conc. HCl-P_o was in average 3% of the total soil P pool. However, Bashour et al.,

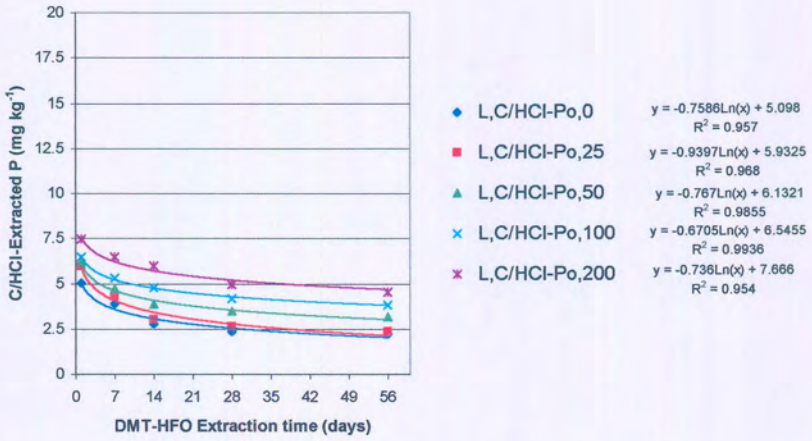

Fig. 16a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 1 day of incubation of Loskop soil

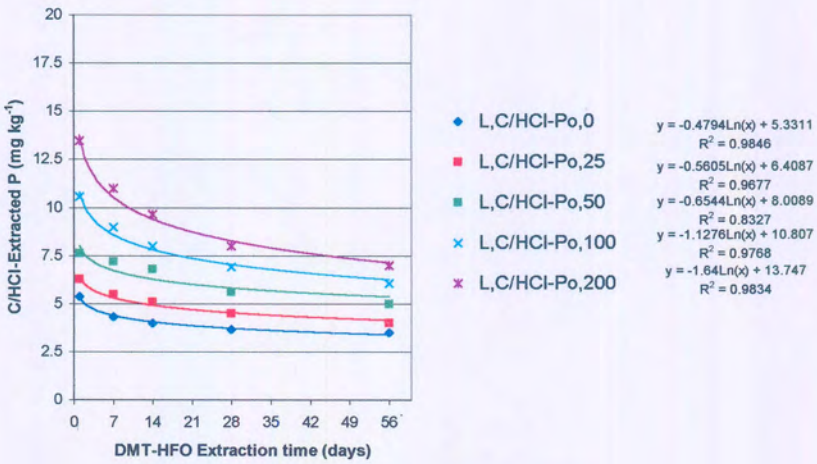

Fig. 16b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 120 days of incubation of Loskop soil

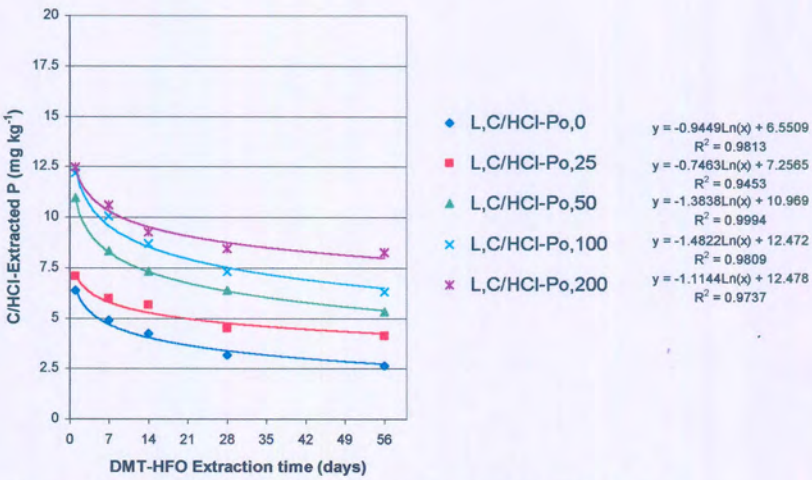

Fig. 16c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 240 days of incubation of Loskop soil

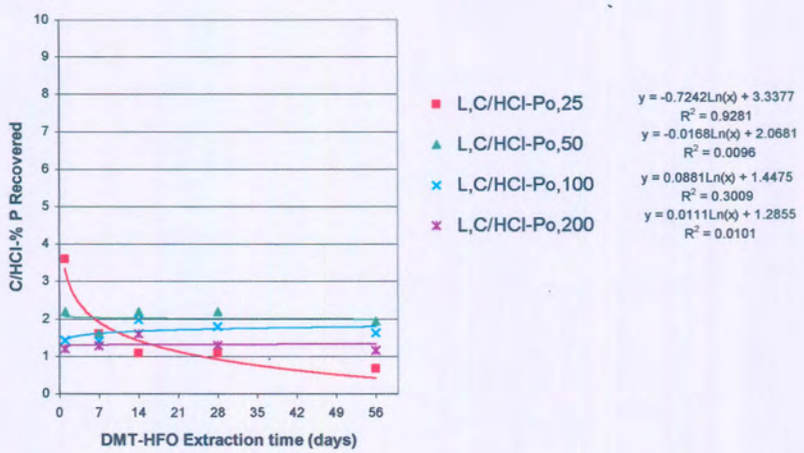

Fig. 16.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 1 day of incubation of Loskop soil

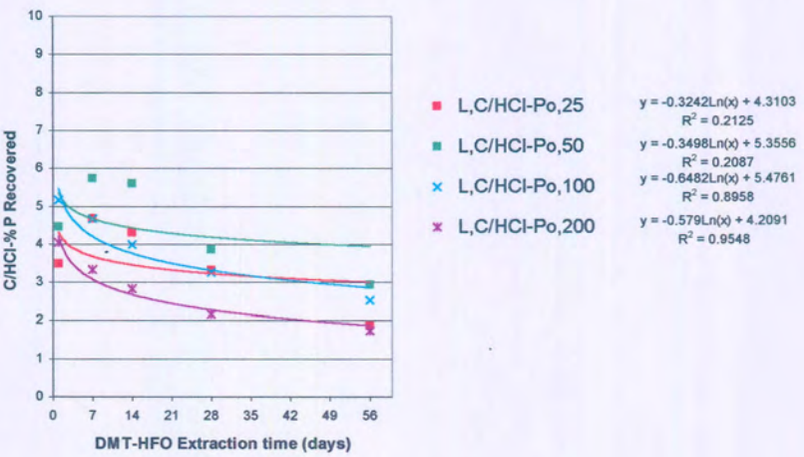

Fig. 16.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 120 days of incubation of Loskop soil

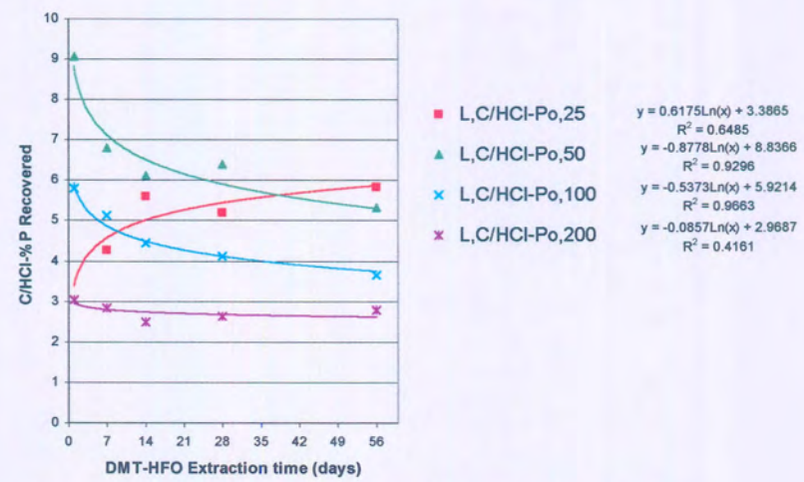

Fig.16.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 240 days of incubation of Loskop soil

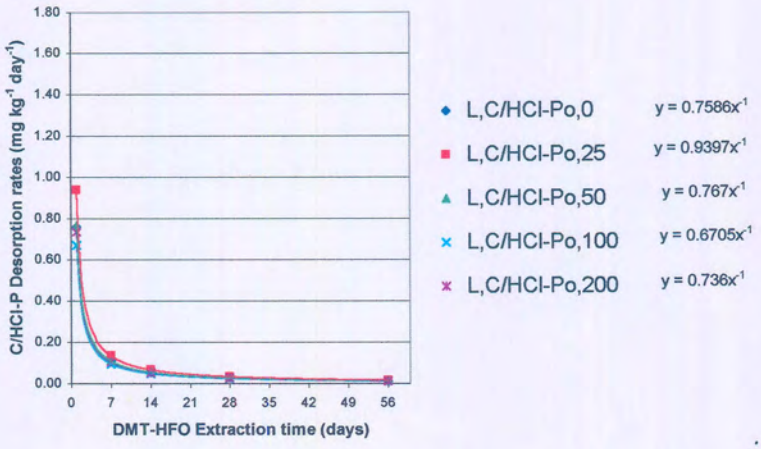

Fig. 16.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

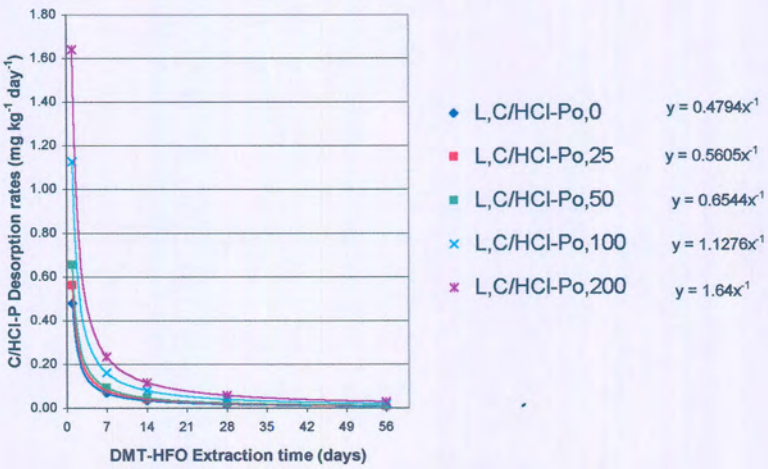

Fig. 16.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

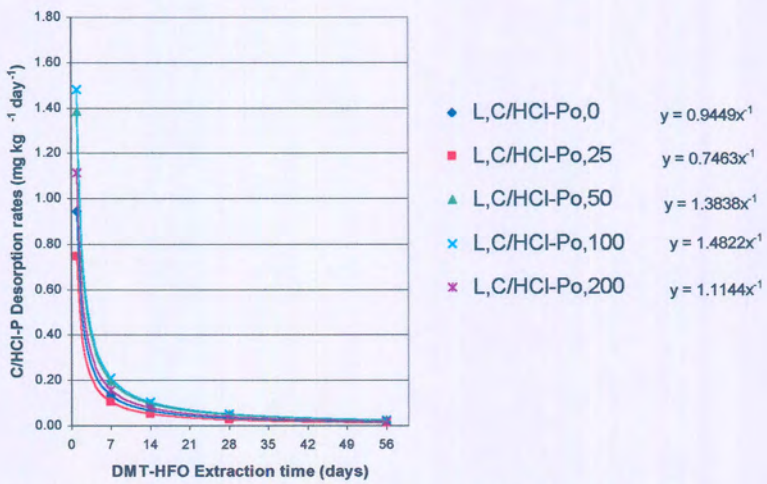

Fig.16.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

(1985) found the amounts of P_o in their samples ranged from 0–90 mg kg^{-1}. These amounts contributed to 0–26.7 % of the total soil P pool. But, Oades and Ladd (1977) reported that as much as one quarter of bacterial cell P was non-extractable from soil, it is possible that the incubation processes would add to the bacterial population and that would result in the slow accumulation in the recalcitrant and residual P fractions. Oades and Ladd (1977) had suggested that the majority of P_o forms in the occluded or residual P_o (C/HCl-P_o extracts) are of larger molecular weight complexes that correspond to the humic acid and humin fractions, which are stable, and not subject to losses with time.

2d: (ii). The changes and distribution of the conc. H_2SO_4 + H_2O_2-P_i extractable P pool (H_2SO_4-P_i) after successive DMT-HFO extractions

2d: (ii). (a) Rustenburg soil

The conc. H_2SO_4 + H_2O_2-P_i extracts (H_2SO_4-P_i) (Tables 1a-3a; Figs. 17, 17.1 and 17.2) varied significantly (P = 0.01) with the successive DMT-HFO extractions (Appendices II No. 6). The amounts of the H_2SO_4-P_i extracted reduced significantly between 1 and 56 days of successive DMT-HFO extractions from 56.67-26.08 and 69.83-46.90 mg kg^{-1} after 1 day of incubation and from 60.83-35.25 and 116.13-86.00 mg kg^{-1} after 240 days of incubation between the lowest and highest P levels (Tables 1a-3a; Figs. 17a-c).

The percent recovery of the added P from the H_2SO_4-P_i extracts were also moderately high, it stabilized at about 10 % after 1 day of incubation and at over 25 % after 240 days of incubation between 25 and 200 mg kg^{-1} applied P (Tables 1a-3a; Figs. 17.1a-c). This indicates relatively higher contributions to the labile P pool than the conc. HCl-extracted P (occluded or insoluble P).

The P desorption rates from the H_2SO_4-P_i extracts were moderate, it thus stabilized at about 7 mg $kg^{-1}day^{-1}$ after 1 day of DMT-HFO extraction and at more than 0.1 mg kg^{-1} day^{-1} after 56 of DMT-HFO extractions between 0 and 200 mg kg^{-1} applied P

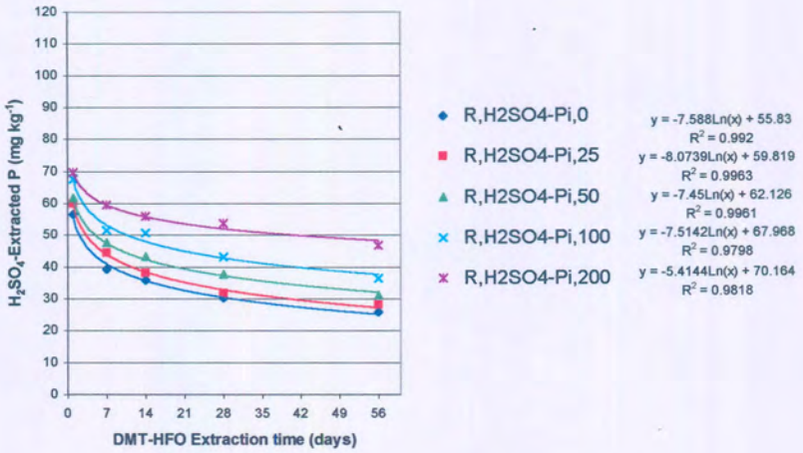

Fig. 17a. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 1 day of incubation of Rustenburg soil

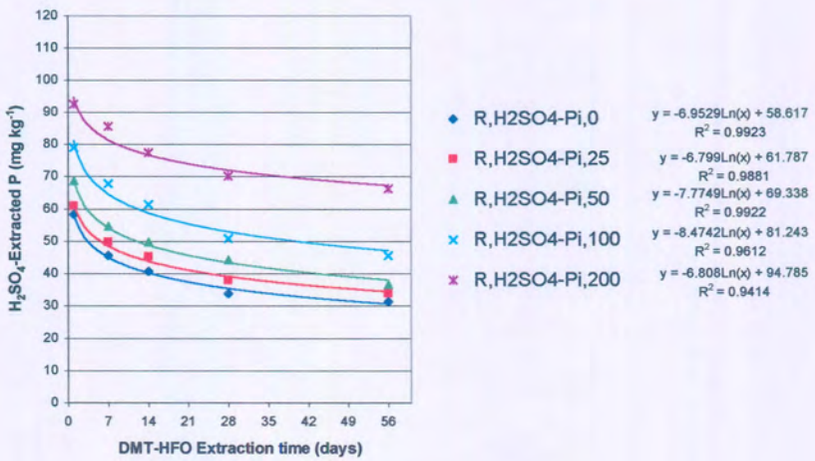

Fig. 17b. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 120 days of incubation of Rustenburg soil

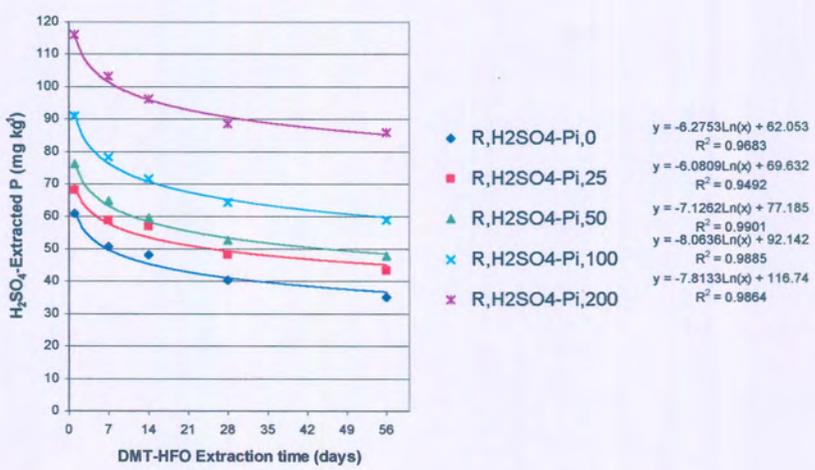

Fig. 17c. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 240 days of incubation of Rustenburg soil

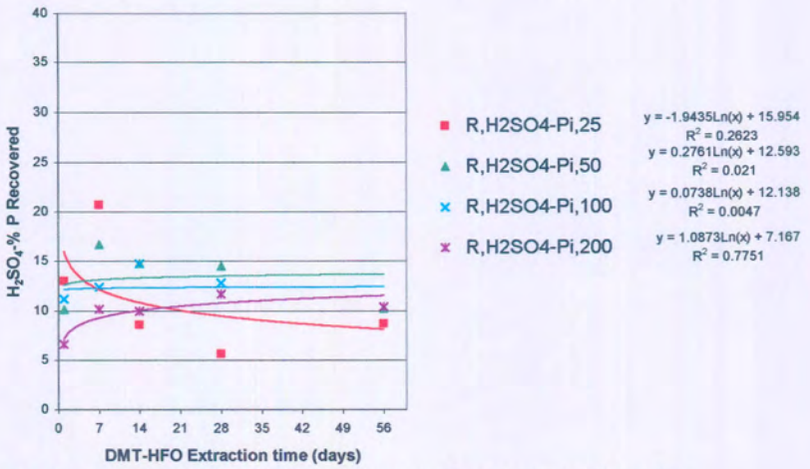

Fig. 17.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 1 day of incubation of Rustenburg soil

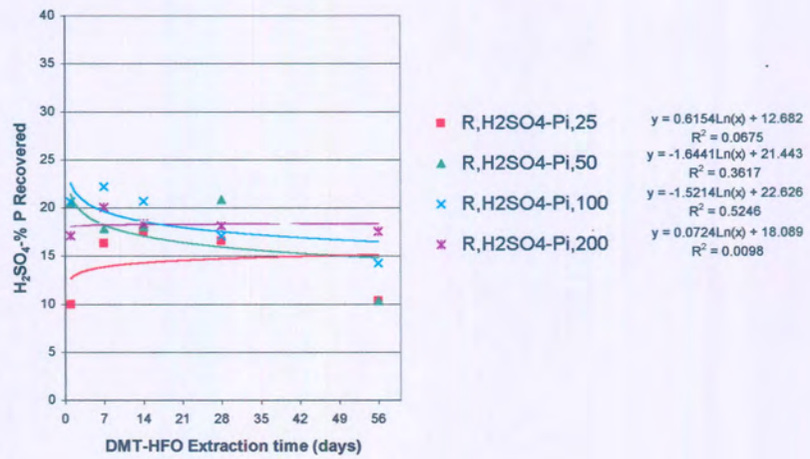

Fig. 17.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 120 days of incubation of Rustenburg soil

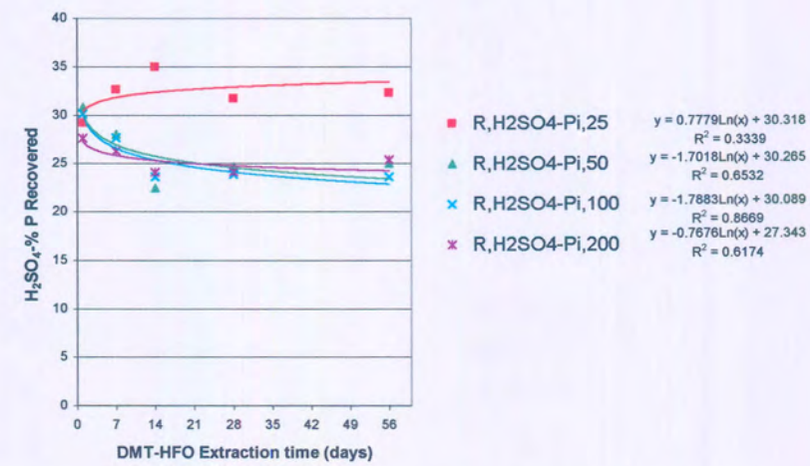

Fig. 17.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 240 days of incubation of Rustenburg soil

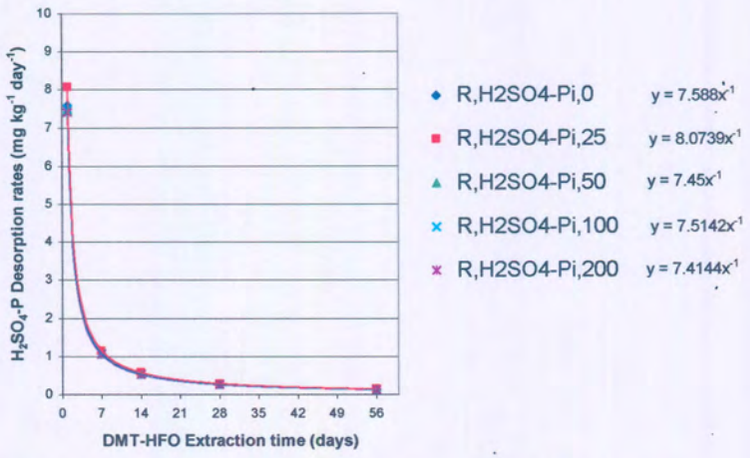

Fig. 17.2a. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

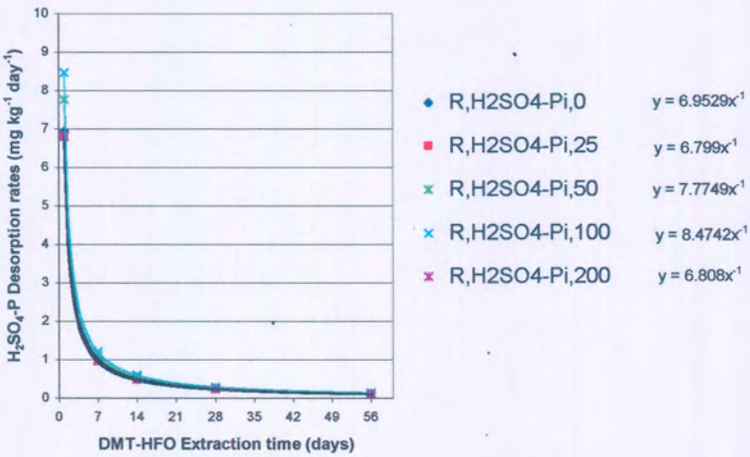

Fig. 17.2b. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

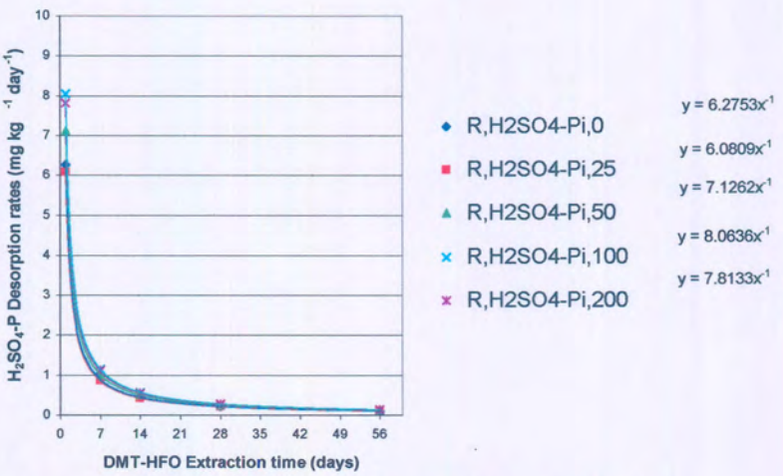

Fig. 17.2c. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

(Figs. 17.2a-c). This indicates some moderate contributions to the labile P pool especially after a prolonged period of time. While the contributions of the H_2SO_4-P_i extracts to the total P pool were the largest at about 25 % in average from 1 to 240 days of incubation (Tables 4a-18a). And, since the H_2SO_4-P_i fraction decreased with the successive DMT-HFO extractions, this would suggest that this pool could be made available to plants after continuous cropping over time.

2d: (ii). (b). Loskop soil

For the Loskop soil, the corresponding values for the H_2SO_4-P_i extracts after the successive DMT-HFO extractions were again lower than the values for the Rustenburg soil. The values reduced from 45.75 to 23.78 and 53.87 to 37.22 mg kg^{-1} after 1 day of incubation and from 47.75 to 30.75 and 75.33 to 62.67 mg kg^{-1} after 240 days of incubation from 0 and 200 mg kg^{-1} added P (Tables 1b-3b; Figs. 18a-c). The percent recovery of the added P was much lower averaging 4 % after 1 day of incubation and 10 % after 240 days between 25 and 200 mg kg^{-1} applied P. This shows lower contributions to the labile P pool and availability to plants compared to the Rustenburg soil (Tables 1b-3b; Figs. 18.1a-c).

The P desorption rates were also lower than of the Rustenburg soil averaging 4 5 mg kg^{-1} day^{-1} after 1 day of DMT-HFO extractions and about 0.08 mg kg^{-1} day^{-1}after 56 days of successive DMT-HFO (Figs. 18.2a-c). However, the contribution to the total soil P pool was relatively as high as for the Rustenburg soil averaging 20 % between 1 and 240 days of incubation following the successive DMT-HFO extractions (Tables 4b-18b).

Figures 18a-c and 18.1a-c show that like for the Rustenburg soil, no apparent equilibria were reached. Further, in comparison to the Rustenburg soil, relatively smaller amounts of H_2SO_4-P_i were extracted from all the treatment levels, indicating that less residual and lattice P was held initially or subsequently adsorbed by the Loskop soil. And, since the H_2SO_4-P_i fractions in the two soils reduced substantively with the successive DMT-HFO extractions, this suggests that some of the P in this

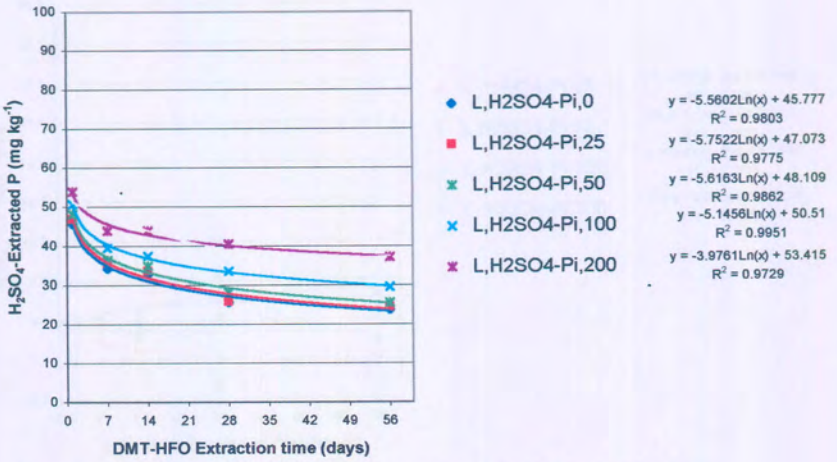

Fig. 18a. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 1 day of incubation of Loskop soil

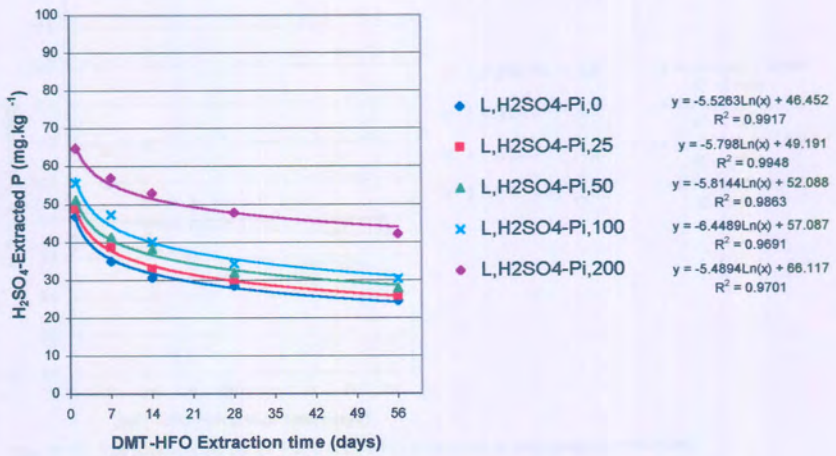

Fig. 18b. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 120 days of incubation of Loskop soil

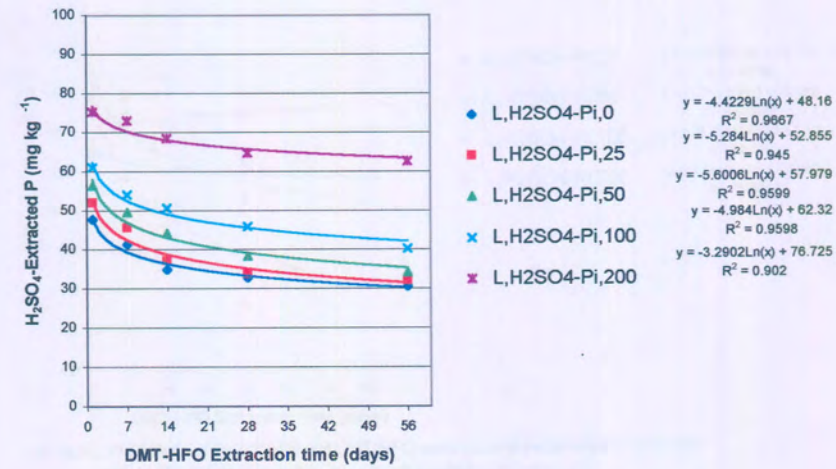

Fig. 18c. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 240 days of incubation of Loskop soil

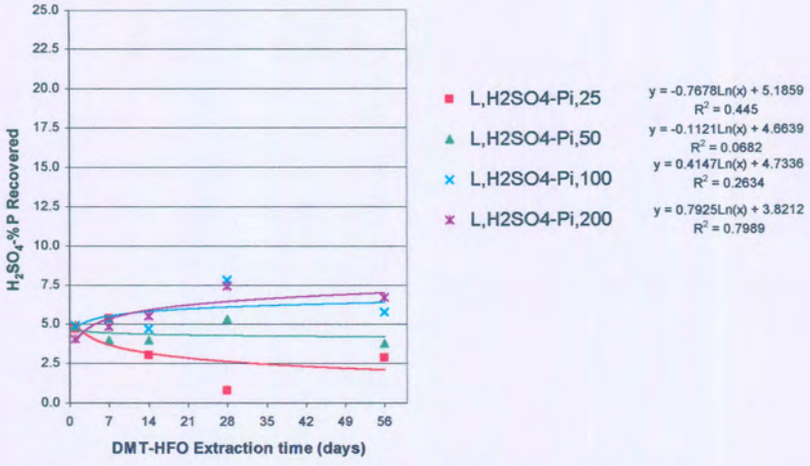

Fig. 18.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 1 day of incubation of Loskop soil

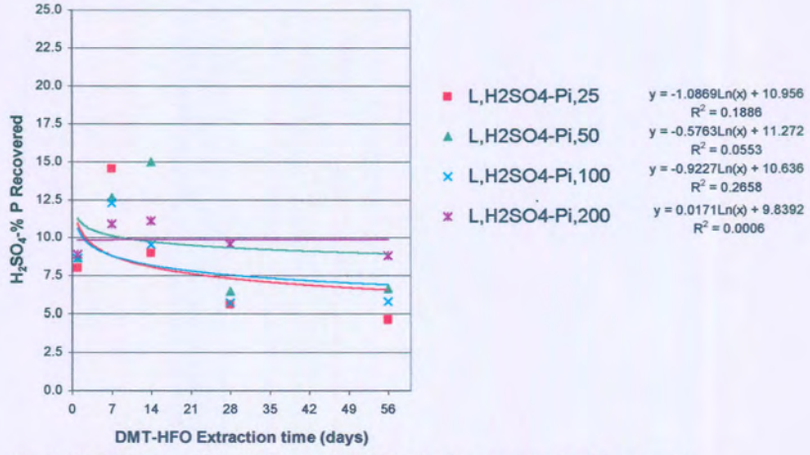

Fig. 18.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 120 days of incubation of Loskop soil

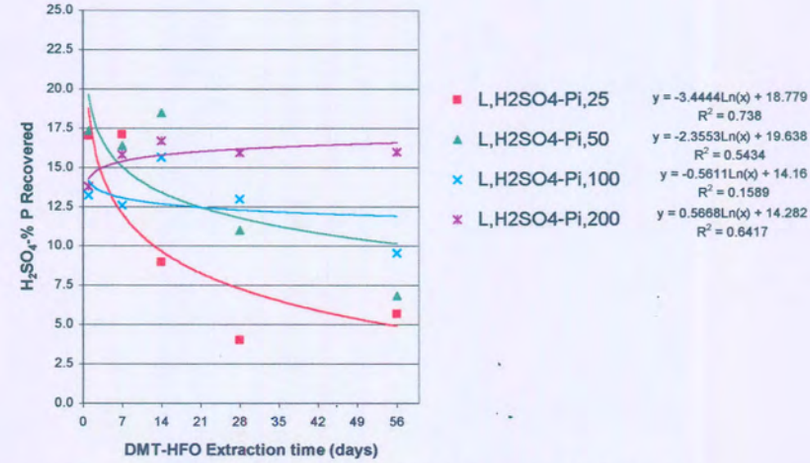

Fig. 18.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 240 days of incubation of Loskop soil

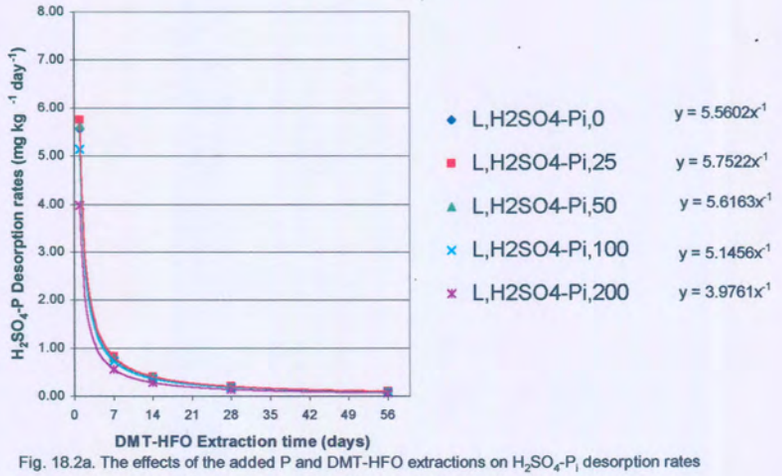

Fig. 18.2a. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

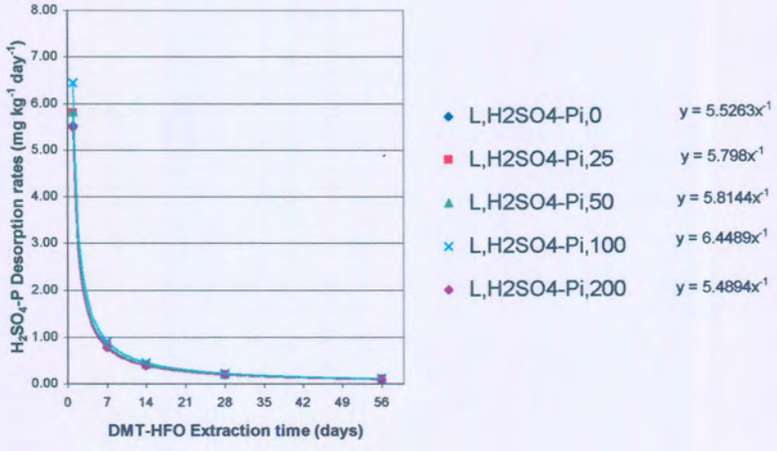

Fig. 18.2b. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

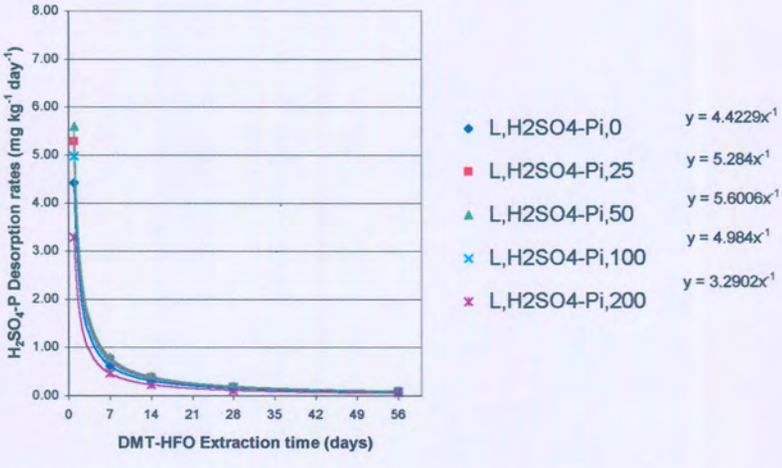

Fig. 18.2c. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

fraction were present in the forms that were transformed into the labile P pool over time. It therefore shows that this pool also acts as a limited source of labile P for field crops after prolonged period of continuous cropping.

As it has already been indicated, the H_2SO_4-P_i fraction consists of mainly stable humus and humic acid, and relatively insoluble P_i forms. This includes P_i present within highly crystalline oxides and hydrous oxides of Fe and Al, and in the highly insoluble P minerals such as plumbogummites ($XAl_3(PO_4)(OH)_5.H_2O$), where X=Pb, Ba, Sr, Ca, or Ce, or it may also consist of occluded apatite and lattice P (Walker and Syers, 1976; Hedley et al., 1982; Wager et al., 1986). Since the H_2SO_4-P_i fractions in the two soils decreased with the successive DMT-HFO extractions, this would suggest that some of this fraction was present in the forms that could be utilized over time.

Total insoluble and residual P pool (conc. HCl-P_i and H_2SO_4-P_i extracts)

The combined values for the conc. HCl-P_i and H_2SO_4-P_i extracts as the relatively insoluble P fractions showed that Rustenburg decreased (between 1 and 56 days of extractions) from 114.55 to 74.49 (40.06) after 1 day and 153.51 to 103.29 (50.22) mg kg^{-1} after 240 days of incubation. These also caused reduction in P recovery of 43.63-41.54 (2.09) % (1 day) and 52.00-51.27 (0.73) % after 240 days of incubation. While the Loskop soil values were only reduced from 83.75 to 57.24 (26.51) (1 day) and 103.89 to 73.97 (29.92) mg kg^{-1} (240 days). The reductions in percent P recovery were 36.96 to 33.53 (3.43) (1 day) and 44.10 to 40.31 (3.79) % after 240 days incubation (Tables 4-18).

These results show that the largest proportion of the total soil P pool in both soils consisted mainly of relatively insoluble P_i (occluded and residual P) forms and stable humus and humic acids (Wager et al., 1986). But, the reductions (percent recovery) of the conc. HCl-P_i and conc. H_2SO_4-P_i in the soils, following the successive DMT-HFO extractions were not as large as the proportion these two fractions occupy as fractions of the total soil P pool. However, the noted reductions suggest that some of

the constituents of these fractions were present in forms that crops are able to utilize under field conditions. The crops probably utilize some of the forms especially in the H_2SO_4-P_i fraction (that showed larger reductions) after some cropping sequences.

It has also been suggested that the conversion of the fixed P to a form that is exchangeable may occur during the cropping process. Plant roots excrete organic acids into the soil and it appears possible that this may be an important mechanism by which plant roots extract phosphate from the surface of soil particles. Further, during crop growth, specific root processes, such as the release of H^+ ions due to cation uptake, may also be responsible for solubilizing the relatively insoluble Ca-P_i, and residual P_i forms (Tiessen et al., 1984).

CONCLUSIONS

In this study an attempt was made to investigate the rate of transformations and distribution of the applied P and the desorption rates. The method consisted of successive DMT-HFO extractions. It was noted that the desorption curves of the two soils had not reached plateaux for either soil, indicating that desorption could continue for a much longer period than the 56 days of DMT-HFO extractions used in this experiment. At the end however relatively small quantities of P were extracted. This property could be relevant for the crops in the field with respect to the residual effect of added fertilizer P and could thus be important in the economical management of fertilizer applications rates. Although Rustenburg soil is shown to be a high P fixing soil the P release rates are still high enough to meet the cotton and tobacco plants requirements. The problems could be attributed to the root systems of the crops grown, which fail to exploit the soil volume well in order to extract P efficiently and thus experience P deficiencies.

The DMT-HFO-P_i accounted for a small fraction of the total soil P pool for Rustenburg but was relatively higher for Loskop soil. Very close relationships were shown to exist between the total amounts of P released during the different DMT-HFO extraction times and -HCO_3- and -OH-extractable soil P_i. Thus, to maintain a given rate of solution P release, greater labile and moderately labile soil P contents are necessary. Notable decreases were also recorded for insoluble and residual P (conc. HCl and H_2SO_4 extracts), showing some contributions to the solution P_i from these pools over time. The effects of incubation on the applied P in both soils resulted in increases in P concentrations mainly into –OH-P_i pool and the insoluble (conc. HCl and H_2SO_4-P_i) pool. They represented the largest proportions of the total soil P pool.

The results showed that all the stable soil P pools contributed to the solution P_i pool by different proportions after prolonged extraction time. This indicates that stable soil P pools are able to contribute to the solution and possibly labile P pools after successive cropping sequences in the fields. It was shown that the P desorption rates

for both soils were initially very fast (between 1 and 14 days of extractions) and then proceeded very slowly for a long period of time with seemingly no apparent end in point. The fast reaction was observed to account for a significant portion of the overall change in solution P concentrations.

The data showed that over 80 % of the total soil P could be recovered with DMT-HFO, -HCO_3, and –OH extracts. In future efforts could be made to use relatively stronger extracting reagents in order to account for proper P availability to crops. This research has shown that simple chemical extractants cannot be used effectively to assess the potential P desorption rates because they do not include all the slowly (labile) available P from different P pools.

It has been shown that at the beginning of the incubation period most P was in DMT-HFO, -HCO_3, and –OH pools. After longer incubation periods more was extracted from conc. HCl and H_2SO_4 pools. This confirms how the applied P was transformed and distributed to the different P pools over the incubation period.

CHAPTER 4

SUMMARIES AND CONCLUSIONS

The changes and the distribution of the initial and applied P into the different P pools

The changes and distribution of the initial and applied P into the different P pools in the two soils, a red-sandy clayey soil (Ferric Luvisols) from Rustenburg (high P fixing) and a red-sandy loam soil (Ferric Acrisols) from Loskop (low P fixing) were the subjects of this first experiment. The changes and distribution were examined by sequential P fractionations to determine (a) plant-available P, (b) adsorbed P, and (c) insoluble and residual P after treatments with different P rates (0, 25, 50, 100, 150, and 200 mg kg^{-1}), and incubation times (1, 60, 120, 180, and 240 days) under laboratory conditions.

The sequential P extractions identified the quantity of P in the different P pools after different incubation periods, and how much of the added P could be recovered. In total nearly 100 % of soil P could be extracted through the different extractions. The percent P in each pool changed with time of incubation. Between 20 and 30 %, and 20 and 35 % of the P could be extracted with HFO extract, while between 20 and 40 %, and 20 and 35 % with the $-HCO_3$ extract after one day of incubation from Rustenburg and Loskop soils respectively. This indicates that approximately 30 to 60 % of the added P were transformed into less labile pool after 1 day. Within 60 days between 80-90 % was transformed to the less labile P pools. This transformation was faster in the Rustenburg than the Loskop soil. A major part of the P transformation was to the –OH-P. The recovery from this pool was fairly constant for the different incubation periods (approximately 30 %). The percentage recoveries in the other pools increased up to 60 or 120 days where after the increases were less for longer incubation periods.

Thus, while solution and labile P decreased with time of incubation, there were corresponding increases in adsorbed, occluded and residual P. In total this transformation in Loskop soil was less than for the Rustenburg soil. The noted differences could explain the reportedly higher levels of P fixation (adsorption and/or precipitation) by the Rustenburg soil than by the Loskop soil. With increasing P supply levels the percentage recovery into the labile P pools decreased in both soils.

Therefore, for efficient utilization of fertilizer P especially in the Rustenburg soil, band placement at planting time could be recommended. This recommendation is based on the assumption that the P sorption capacity would become saturated in the vicinity of the band and that some of the added P would remain available to the plants. The use of plants with well-developed root systems could also be recommended to ensure that it explores the soil volume more effectively.

It should also be noted that the changes of P in soils are complex, and although the added fertilizer P is transformed to more stable (immobile) P forms, it could be seen as long-term residual P pools for plants. Thus, having determined the extent of P fixations by the two soils, it became necessary to establish how much of this transformed or fixed P can become available to plants over time and at what rate.

The successive DMT-HFO extractions, transformations of applied P, desorption rates, and contributions of different P pools to the labile P pool

In the second laboratory study an attempt was made to investigate the rate of transformations and distribution of applied P and desorption rates. The method consisted of successive DMT-HFO extractions followed by sequential P fractionations to determine the changes in the different P pools. In this experiment it was noted that the cumulative P extraction curves of the two soils had not reached plateaux, indicating that desorption could continue for a much longer period than the 56 days of DMT-HFO extractions used in this experiment. At the end however, relatively small quantities of P were extracted. It was further noted that the rates of P desorption by the two soils were initially fast (between 1 and 14 days of extractions)

and then proceeded slowly for a long period of time with seemingly no apparent end in point, in most cases. This property could be relevant for the crops in the field with respect to the residual effect of added fertilizer P. Thus, knowledge of the type of cumulative P extraction curve, which the soil has, could be important in the economical management of fertilizer applications rates.

The DMT-HFO-P_i accounted for a small fraction of the total soil P pool for Rustenburg but was relatively higher for Loskop soil. The percentages increased with the DMT-HFO successive extractions and the added P levels, but were markedly reduced by the increasing days of incubation. Examinations of the curves show that the highest percent DMT-HFO P recovered from both soils were after the first day of incubation. Increasing incubation time resulted in a decrease in the DMT-HFO P recovered in both soils, but more especially for Rustenburg soil, confirming that the Rustenburg soil has a higher P fixing capacity.

In practical terms the P release rate can be evaluated when it is considered that both tobacco and cotton crops remove approximately 15 kg P ha^{-1}. Their requirements can be met by the two soils, since both soils are able to release between 0.4-0.5 mg kg^{-1} day^{-1} after 56 days of successive extractions. This represents a P release rate of approximately between 1.7 and 2.2 kg P ha^{-1} day^{-1} (soil depth = 30 cm; bulk density = 1 500 kg m^{-3}). The results therefore showed that although Rustenburg soil is considered to be a high P fixing soil the P release rates are still high enough to meet the cotton and tobacco plants requirements. The problems could be attributed to the root systems of the crops grown, since if the roots do not develop extensively enough to be able to exploit the soil volume well in order to extract P efficiently, plants may experience P deficiencies.

Further, P desorption rate after 56 days DMT-HFO extractions may seem low, but it should also be realised that in practice in the field the crop requirements at the beginning of the growing season is small and the extraction rates (P uptake) will thus be smaller. It means that if less P had been extracted during the first 14 days of extractions, the desorption rates would not have decreased so much over the first 14

days but over a longer period. This assumption is made because over the 240 days of incubation there were less P extracted over the 56 days but the changes in desorption rates were quite similar. The total amount of P extracted also indicates that both soils were able to supply enough P over the growing seasons for both cotton and tobacco crops.

The results of this research indicated that the single extractions that are presently used for determining the available P in the routine soil analysis are ineffective to measure accurately the quantity of P available to crop plants. The data showed that the immediately available P pool was constantly replenished through reactions of dissolution or desorption of less available P, as well as the mineralization of organic P. The pool size of total available P was therefore strongly time dependent. Thus, by separating soil P into fractions characterized by their mode of extraction, it is possible to identify the soil P fractions, which are altered over time by the incubation experiments.

Each of the extracts obtained can be assigned to describe the quantity of P different in its availability to plants. These empirical assignments can then be used to characterize P status of soils as a conceptual model of P pools, their availability to plants, and their transformations into different P pools. From this, the distribution of P in soils can be studied, i.e. P moving to less labile P_i or P_o pools and the dissolution/desorption of less labile P_i and mineralization of P_o pools.

Over 80 % of the total soil P could be recovered with DMT-HFO, -HCO_3, and –OH extracts. In future efforts could be made to use relatively stronger extracting reagents in order to account for proper P availability to crops. This research has shown that simple chemical extractants cannot be used effectively to assess the potential P desorption rates. This is because they do not provide adequate information on the soil P status, especially in terms of the long-term capacity of the soil to supply P for plant growth, since they do not include all the slowly (labile) available P from different P pools.

Since the use of DMT-HFO does not disrupt the chemical structure of the soil, it is possible to make a series of extractions from one soil sample allowing the examination of desorption characteristics of soil P over a period of time simulating plant P uptake. This method approximates a biological measure, and thus represents a useful analytical tool to predict the effectiveness of applied P fertilizers and the availability of residual P in soils. As it estimates more accurately the labile P pool, it is therefore probably a better indicator of plant available P, which more closely reflects the processes involved in P uptake by plant roots in soil.

However, although the method is ideal for evaluation of plant available P over a longer period of time, it would not be practical to use as a routine soil analysis as it is expensive and time consuming. Further, in this laboratory method the total soil volume of the sample was extracted. In practice however, the root system does not occupy 100 % of the soil total volume. Also, a lot more P is desorbed between 1 and 14 days of extractions while in practice in the field the plant roots would just be developing. Therefore, in order to implement this procedure a model to describe root development that represents the percentage of the soil exposed will be necessary.

It is envisaged that by using this method the P releasing properties of a soil could be used to develop a P desorption model. With such a model it could be possible to determine how much extractable P, with a specific extractant, in a particular soil, should be available at the beginning of a growing season to be suitable to have a high enough P releasing rate to meet the requirement of a certain crop up to the end of the growing season.