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The dynamics of phosphorus extractability, adsorption, and desorption rates as influenced by phosphorus applications and incubation times

by

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Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

in the

DEPARTMENT OF PLANT PRODUCTION AND SOIL SCIENCE
FACULTY OF NATURAL AND AGRICULTURAL SCIENCES
UNIVERSITY OF PRETORIA
PRETORIA

April 2002

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DEDICATION

This work is dedicated to the fond memories of Veronica Awor, Salmon Obbo, Simon Onyango, Matayo Owora, and Maltilda Nyafwono.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Prof. E.N. Sabiiti, the Dean, Faculty of Agricultural Sciences, Makerere University, and the National Agricultural Research Organization (NARO) Uganda, for the financial support that enabled me to undertake this study. I am equally grateful to Prof. P.J.M. Ssebuwufu, the Vice-Chancellor, Makerere University, for granting me study leave. I wish to thank Dr. D.G. Joubert, Director, ARC – Institute for Industrial Crops, Rustenburg, for allowing me to carry out this research at his Institute, providing me with a decent accommodation facility, and for the provision of research facilities and technical support.

I am highly appreciative to my supervisor Prof. A.S. Claassens for having been a constant source of inspiration and guidance. I wish to sincerely thank him for his friendship, kindness, encouragement, and inspiring discussions. I further, wish to express my sincere thanks to Ms. Elise Eulitz for kindly assisting me with the statistical analysis, and to Ms. R. Steyn and Ms. D. Venter for giving me some very valuable lessons on computer applications and to Ms. Alfreda Pohl for proof-reading part of the draft. My special thanks go to Mr. A. Cornelissen for the brotherly love, technical, and moral support he unreservedly afforded me for the duration of my stay in South Africa.

Special appreciations also go to Mr. H. Boshoff, Dr. M. Dippenaar, Dr. C.J. Steenkamp, C. de Jager, Mr. J. Tlou, Ms. K. Smook, Ms. M. Venter, and Ms. N. Meyer for the technical assistance they offered me. I wish also to thank my friends Gloria Poonyane, Simon Molope, Thomas Areke, John Ramashala, Ismail Moosa, Johannah Molwantwa, and all other colleagues at the IIC, Rustenburg and the University of Pretoria, for their assistance and friendship, and for making it possible for me to enjoy my stay at the Institute.

Last but definitely not least I want to thank my family and especially my wife Virginia M. Ochwoh, my daughters Nicky Nyafwono, Lilian Akoth, Rovita Nyamwenge, and Phyllis Awor, and my son Simon Onyango for their physical and moral support, encouragement, and patience without which the research and therefore this thesis would not have been completed.

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ABSTRACT

In a study to investigate the fate of the applied P in 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 used. Sequential P fractionations were used to determine the content of the different P pools to show which pool the applied P was transformed to. The soils treatments consisted of different P rates (0, 25, 50, 100, 150, and 200 mg kg^{-1}), and incubation periods (1, 60, 120, 180, and 240 days) under a laboratory conditions. The sequential P fractionation procedure consisted of extraction with hydrous ferric oxide in a dialysis membrane tube (DMT-HFO), 0.5M $NaHCO_3$, 0.1M NaOH-P, 1.0M HCl, concentrated HCl, and concentrated H_2SO_4 + H_2O_2.

Approximately 30 to 60 % of the added P were transformed into less labile P pools within one day and 80-90 % after 60 days. This transformation was faster in the Rustenburg than in the Loskop soil showing a higher P fixation capacity. A major part of the P transformation was to the –OH-P_i pool with a recovery of about 30 %.

In the second experiment an attempt was made to determine P desorption rates by successive DMT-HFO extractions (1, 7, 14, 28, and 56 days) after the transformations of the applied P. This was followed by the sequential extractions to determine the changes and distribution of the added P into different P pools as well as which pools the P was desorbed from. The Rustenburg and Loskop soils were treated to different P rates (0, 25, 50, 100, and 200 mg P kg^{-1}) and incubation periods (1, 120, and 240 days).

The cumulative DMT-HFO extraction curves for 56 days showed that desorption could continue for a much longer period. This property is important in the economical management of fertilizer applications rates. Results showed the transformations and distribution of the applied P during incubation periods and proved that all the stable soil P pools contributed to the labile P pool by different proportions after prolonged successive DMT-HFO extractions.

Although Rustenburg soil is considered a high P fixing soil, the P release rates under laboratory conditions were high enough to meet the requirements of cotton and tobacco crops. Root systems of these crops do not exploit 100 % soil volume as this laboratory method, which could explain why these crops experience P deficiencies.

It is envisage that by using this method the P releasing properties of a soil could be used to develop a P desorption model 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 sustain a high enough P releasing rate to meet the requirements of a certain crop up to the end of the growing season. To do this, a model to describe root development that represents the percentage of the soil exploited P desorption rates that simulate P uptake by plant roots will be necessary.

Keywords: Adsorbed P, immobile and residual P, labile P, labile and stable P pools, P adsorption and desorption, P desorption rates, P fractionations, P percent recovery, P transformations and distribution, sequential P extractions.

UITTREKSEL

In 'n studie om die transformasie van die toegediende P te ondersoek, is 'n rooi sanderige-klei grond (Ferriese Luvisol) van Rustenburg (hoë vasleggingspotensiaal) en 'n rooi sandleem grond (Ferriese Acrisol) vanaf Loskop (lae P-vasleggingspotensiaal) gebruik. Verskillende vlakke van P (0, 25, 50, 100, 150, en 200 mg kg^{-1}) is toegedien en vir verskillende tye geinkubeer (1, 60, 120, 180, en 240 dae). Opeenvolgende fraksionerings is gedoen om die P-inhoud van verskillende P-poele te bepaal om aan te dui waarheen die toegediende-P omgeskakel is. Die opeenvolgende fraksionerings het bestaan uit ekstraksies met ferrihidreerde ysteroksied in dialisemembraanbuise (DMT-HFO), 0.5 $MNaHCO_3$, 0.1 M NaOH, 1.0 M HCl, gekonsentreerde HCl en gekonsentreerde $H_2SO_4 + H_2O_2$ – P.

Tussen 30 - 60% van die toegediende P is getransformeer na minder labiele P-poele en het verhoog tussen 80 - 90 % na 60 dae. Die transformasie was vinniger in die Rustenburg- as in die Loskopgrond en vertoon dus 'n hoër P- vasleggingsvermoë.

In die tweede eksperiment is daar gepoog om vas te stel wat die desorbsie tempo van toegediende P is nadat transformasie plaasgevind het. Dit is opgevolg deur opeenvolgende ekstraksies om te bepaal uit watter P poele die P geekstraheer is. Die twee grondtipes van Rustenburg en Loskop is behandel met verskillende P-toedienings (0, 25, 50, 10, en 200 mg P kg^{-1}) en inkubasie-tye (1, 120 en 240 dae).

Die kumulatiewe ekstraksies met DMT-HFO vir 56 dae het aangetoon dat desorbsie vir langer periodes kon plaasvind. Hierdie eienskap is belangrik vir die ekonomiese bestuur van kunsmistoedienings. Die transformasies en verspreiding van toegediende P en inkubasie tye dui daarop dat die stabiele grond- P-poele bygedra het tot die labiele P-poel.

Alhoewel die Rustenburg grondtipe 'n hoë P-adsorbsie kapasiteit het, is die P-vrystelling voldoende om aan die behoeftes van katoen en tabak te voldoen. Die wortelstelsel van die gewasse benut die grond egter nie tot in dieselfde mate as wat met die laboratorium metode bereik word nie en ondervind die plante P-tekorte.

Met behulp van die desorpsie tempos sou dit moontlik wees om 'n model te ontwikkel, waarmee voorspel kan word hoeveel ekstraheerbare P met 'n sekere ekstraksiemiddel nodig sal wees aan die begin van die groeiseisoen om te voldoen aan die P behoefte van 'n gewas aan die einde van die groeiseisoen.

Om hierdie metode te kan implementeer sal die wortelontwikkeling van 'n gewas in aanmerking geneem moet word om te bepaal watter persentasie van die grond deur die wortels geekstraheer word.

Sleutelwoorde: adsorbeerde-P, onbeweeglike- en residuele-P, labiele-P, labiele en stabiele P- poele, P- adsorpsie en desorpsie, P- desorpsie-tempo, P-fraksionerings, P- persentasie herwinning, P- transformasie en verspreiding, opeenvolgende P- ekstraksies.

CHAPTER 1

GENERAL INTRODUCTION

Background

Phosphorus deficiency in plants is believed to constitute the second most important soil fertility problem throughout the world (Sanchez and Salinas, 1981; Lindsay, Vlek and Chien, 1989). Sanchez (1976), Pushparajah and Bachik (1987), Sattell and Morris (1992), and Doula, Ioannou and Dimirkou (1996) have all indicated that phosphorus was the second most limiting element in the Alfisols, Oxisols, and Ultisols of tropical Africa, Asia, and South America. Phosphorus deficiency in such soils is often exacerbated by a high capacity to fix phosphates in different ways making P less available to crops. Most of these soils are often rich in Fe and Al 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). As phosphate fertilizer is one of the most expensive inputs, it is essential not only to know the most cost effective phosphate application rates but also the long-term effects of the added phosphate in the soil. Therefore, the acquisition of precise information concerning soil phosphate availability is a prerequisite to ensure sustainable management of soil.

The P fractionation procedure to characterize different P fractions in fertility studies was used by Chang and Jackson (1957). Only inorganic P was characterized, due to the lack of proper methodologies to identify organic P fractionations at the time. The progressive importance given to the organic P fraction made it necessary to look for more comprehensive fractionation procedures. A procedure was thus, proposed which allowed for a more complete characterization of soil P than the previous procedures (Hedley, Steward and Chauhan, 1982). This procedure has been used in different soils to study the transformations and distribution of inorganic and organic P forms (Vazquez, Noellemyer and Coremberg, 1991). Tiessen and Moir (1993) regrouped the P fractions based on the rates of their recovery or transformations into different inorganic P pools. This allowed for the development of a more dynamic picture of P transformations in the soils.

There could be a significant residual effect due to the possible desorption of phosphate from the different soil components and when this benefit is ignored it could lead to unnecessarily high P applications (Quang et al., 1996). The residual plant-available P in soils can be quantified by successive cropping experiments carried out in field or greenhouse conditions. 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 extractants cannot be used to assess the potential desorption rates of P, because they disrupt the chemical structure of soils. Some soil test methods that have limited effects on the soil system that include isotopic exchange techniques, anion exchange resins, iron oxide-impregnated paper strips, and dialysis membrane tubes filled with hydrous ferric oxides (DMT-HFO) have been proposed (Amer et al., 1955; Dalal, 1985; Menon et al., 1990; Freese et al., 1995). These methods extract more of the "plant-available P" than the chemical procedures. Successive extractions carried out by any of these methods may constitute a convenient laboratory method to characterize the capacity of soil to supply P, and to investigate the rates of P release from original and P fertilized soils over a period of time (Indiati, 1998).

Phosphorus status of South African soils

In South Africa, P deficiencies due to P sorptions are widespread especially in highly weathered soils in the high rainfall areas (Reeve and Sumner, 1970; Mcgee, 1972; Bainbridge, Miles and Praan, 1995). Within such areas P deficiency is reported to be the most common and economically important nutritional deficiency. The studies of Reeve and Sumner (1970) revealed a wide variation in the P sorption capacities of some Oxisols in Kwazulu-Natal Province. Similarly Mcgee (1972), in evaluating P sorptions in soils of Gauteng, Mpumalanga, Northwest, and Free State Provinces found considerable variations in their sorption capacities. Bainbridge et al., (1995) in an effort to quantify the P sorption capacities of soils in Kwazulu-Natal Province determined the P-sorption isotherms of 50 soil samples from a number of localities in the province. They found that the amounts of P sorbed ranged from 5 - 1174 mg kg^{-1} and that the highest sorptions occurred in the highly weathered red and yellow-brown clay soils with a high organic carbon contents in the A horizon (Inanda, Kranskop and Magwa forms). This agrees with the findings of Haynes (1984) who had indicated that ferric and aluminium ions complexed with organic matter provide additional sites for P sorption.

Although P sorption has been found to increase with increasing soil clay content, a considerable variation in sorption capacities have been obtained in different soils with similar clay contents (Johnson, Miles and Thiabau, 1991). It has been shown further that, soils with predominantly 1:1 type clay materials (i.e. highly weathered red and yellow-brown clay soils) sorb far much more P than the soils with predominantly 2:1 type clays. Johnson et al., (1991) also conducted various studies on soils from 54 sites on a wide range of soils in Kwazulu-Natal Province to calculate P requirements and to establish how much P must be applied to overcome any buffering effects and raise the extractable P content to desired levels. In a long-term experiment (over 15 years) on yellowish brown sandy clay loam (Avalon) and a red sandy clay (Clovelly) soil in Ermelo, Mpumalanga Province, du Preez and Claassens (1999), concluded that the NaOH-extractable P (moderately adsorbed P) was mainly responsible for the replenishment of the labile soil P pool.

Phosphorus sorption and desorption characteristics

Phosphorus sorption is the removal of labile P from the soil solution, due to adsorption on, and absorption into the solid phases of the soil, mainly onto surfaces of more crystalline clay compounds, oxihydroxides, or carbonates (Holford and Mattingly, 1975). The labile P forms are also referred to as readily available or plant-available P_i (Hedley et al., 1982). Many highly weathered tropical and subtropical soils can absorb large amounts of phosphates applied as fertilizers, which reduces the nutrient use efficiency of the applied P. Sorption of P is greatest in soils containing Fe- and Al- oxihydroxides, and allophanic clays, followed by kaolinitic and lastly montmorillonitic clays (Sanchez, Palm and Szoth, 1991). Although soil P sorption has been studied intensively relatively less has been done on the P desorptions in soils and sediments. Interests in P desorption studies are rising due to the importance of P on soil fertility and pollution (Sharpley et al., 1985). Intensive animal husbandry in Europe has led to the production of large amounts of animal manures, and the disposals of the manures on agricultural land have led to increased soil P contents (Gerke, 1992). Many soils have become saturated and contributed to surface water eutrophication (Sharpley et al., 1985; Mozaffari and Sims, 1994; Penn et al., 1995; Sharpley, 1996; Pote et al., 1998). Similar problems also occur where sewage sludge has been disposed on land (Gerke, 1992; Sharpley and Sisak, 1997).

P sorption and desorption rates

The rates of P sorptions have received considerable attention over the past years (Freese et al., 1995; Bowman, Rodrignez and Self, 1998). The initial fast P sorption rates are presumably due to reaction with surface sites of metal oxides or hydroxide particles that are exposed to the solution phase. Slow P sorption that continues after the initially rapid sorption is ascribed to the slow diffusion into the soil aggregates (Willet, Chartres and Nguyen, 1988), or due to the slow formation of P containing minerals (van Riemsdijk et al., 1984; Lookman et al., 1995).

The P desorption rates in soils are of particular interests in respects to the bio-availability and the pollution risk as a result of P translocation to deeper layers and by surface runoffs (Pote et al., 1996; Li et al., 1999; Pautler and Sims, 2000). Theoretically, all adsorbed P present in the soil should be desorbable, but in practice, part of the soil P is so strongly bound that it is considered irreversibly fixed (Ryden, McLaughlin and Seyers, 1977; Bowman et al., 1998). A study of the P desorption rates of soil may give more insight to the nature of the plant availability of soil P pools (Lookman et al., 1995).

According to Lookman et al. (1995) little information has been availed on P desorption rates, especially on the long-term. This is due to several practical problems that complicate such long-term studies. In their studies, they classified desorption kinetics into a fast and slow desorbing pools. The fast P pool presumably represents primarily P bound to the reactive surfaces, which are in direct contact with the aqueous phase (Hingston, Posner and Quirk, 1974; Madrid and Posner, 1979). Other possible contributions to the fast desorbing pool may be the less soluble P salts originating from recent fertilizer applications that are not yet in equilibrium with reactive hydrous oxides. Complexed P with organic material may also be part of the fast desorbing pool (Gerke, 1992). The slow P release rates from the second pool are either a result of slow dissolution rates or from slow diffusion from interior sites inside oxihydroxide particles. The sum of the fast and slow pools as defined can be represented by an oxalate extract (P_{ox}) and is an estimate of the total inorganic P in soils that have received a high load of fertilizer (van der Zee, and van Riemsdijk, 1988; Lookman et al., 1995).

The sequential extractions of inorganic-P (P_i) and organic-P (P_o) pools

The applicability of the traditional soil P test procedures that were developed for use in fertilizer application recommendations, especially in agricultural systems with no or low fertilizer P inputs proved inadequate particularly in highly weathered soils (Sanchez et al., 1991). These procedures are basically empirical and yield responses can vary considerably. The sequential P extraction procedures by Chang and Jackson (1957), Hedley et al. (1982), and Tiessen and Moir (1993) have been proposed to improve the estimation of plant-available P. These are methods that use increasingly harsher treatments to extract P pools that are believed to be increasingly less available to plants.

The use of sequential extraction procedures allows different soil P pools to be separated and characterized (extractions by different methods, such as extractions by an anion exchange resin, or dialysis membrane tubes filled with hydrous ferric oxide (DMT-HFO), and P soluble in alkali and acids of varying strengths). This fractionation procedure gives separate soil P pools, which vary in the extent of their availability to the growing plants (Hedley et al., 1982; Tiessen and Moir, 1993).

Classification of P fractions (pools)

(a). The dialysis membrane tubes filled with hydrous ferric oxide (DMT-HFO) or resin-extractable inorganic P (P_i) has been identified as solution P pool, which is readily available for plants;

(b). Extraction with 0.5M $NaHCO_3$ dissolves labile P_i and P_o absorbed on the soil particle surfaces, including a small amount of microbial P (P_o) and represents a fairly labile P pool;

(c). Extraction with 0.1M NaOH dissolves P_i held more strongly due to chemisorption by Fe- and Al- components and moderately labile organic P (P_o). The P_i extracted from these oxihydroxide surfaces, is characterized as moderately labile P_i.

(d). Extraction with 1M HCl dissolves P_i from apatite-type minerals. These are the calcium bound P_i, which exist mainly as hydroxy apatites ($Ca_5(PO_4)_3OH$), fluorapatite ($Ca_5(PO_4)_3F$), and also as dicalcium $Ca(H_2PO_4)_2$ (brushite), $CaHPO_4$ (monetite), tricalcium ($Ca_3(PO_4)_2$), and octacalcium ($Ca_8H_2(PO_4)_6.5H_2O$) phosphates that exist in small amounts as transitional Ca-P forms. The 1M HCl-P_i is thus clearly defined as Ca- associated P_i, as organic phosphorus (P_o) is rarely found in this extract.

(e). Hot concentrated HCl extract has been found useful in distinguishing P_i and P_o in very stable residual pools. However, P_o extracted in this step may also come from particulate organic matter that is not alkali extractable, but readily bio-available. The P_i is mainly from the occluded and recalcitrant (insoluble) P pools. The occluded P has been described as sparingly soluble and is enveloped (occluded) by ferric and aluminium oxihydroxides (Chang and Jackson, 1957, Bowman et al., 1998). The recalcitrant P pool is defined as the resistant or residual P pool, sometimes termed insoluble, immobile, or fixed P and forms part of the lattice P, and may originate from fertilizer P that underwent chemical changes in the soil (Chang and Jackson, 1957; Udo and Ogunwale, 1977).

(f). Hot concentrated H_2SO_4 plus H_2O_2 extract residual P, which contains only highly retained or recalcitrant P_i (such as lattice P) and chemically stable P_o (humus and residual microbial cells) that is strongly retained or fixed P, and is regarded as completely unavailable to plants. This more chemically stable P_o and relatively insoluble P_i forms are dissolved by acid digestion and oxidation with H_2SO_4 and H_2O_2 (Tiessen and Moir, 1993).

The overall advantage of the fractionation of soil phosphates into discrete chemical forms permits the quantification of different P pools, their chemical status in native or cultivated soils and to study the fate of the applied P fertilizers (Hedley et al., 1982, Tiessen and Moir, 1993). Hedley et al., (1982) used this procedure to study the transformations and distribution of P within the soil P pools after incubating the soils. They concluded that the sequential P fractionation procedure could be used to record some transformations in soil P that occur during short-term incubation experiments.

Approaches to characterization of plant-available phosphorus in soils

The plant-available P in soils is a functional concept rather than a measurable quantity, since no simple direct measurements are available. Plant-available P is defined as all the P that can be taken up by a plant during a specific period, such as a cropping season, year or growth cycle. The advantage of using sequential extraction procedures is that P that becomes available slowly over a longer-term can now also be evaluated (Hedley et al., 1982, Tiessen and Moir, 1993).

While P extraction methods for fertility indices have been well established, methods to distinguish and quantify labile and non-labile P such as the occluded and residual

P are less well established (Bowman et al., 1998). Some issues concerning methodology, timeliness and reproducibility of the sequential extraction procedures have not yet been completely resolved. For example, whether the unavailability of the extractable "non-labile P" is the same regardless of the methods of extraction used such as proposed by the sequential extraction methods of Chang and Jackson (1957), Hedley et al. (1982), and Tiessen and Moir (1993). Although such comparisons may not yet have been done, similarities of the results have indicated that some of this so-called non-labile P can be available. Bowman et al. (1998) concluded that reactive surfaces such as oxihydroxides of Fe and Al, and $CaCO_3$ play important roles in the transformations of P in soils from available to unavailable forms or vice versa.

Assessment of P desorption rates in soils

Phosphorus desorption curves are used to evaluate the P desorption rates in soils. It is prepared by using several methods, such as: successive extractions with water or dilute salt solutions (Fox and Kamprath, 1970); extractions of sub-samples with several soil/water ratios (Brewster, Gancheva and Nye, 1975; Barrow, 1979); anion-exchange resin as a P sink (Brewster et al., 1975; Bache and Ireland, 1980; Raven and Hossner, 1994); dialysis membrane tubes filled with hydrous ferric oxide (DMT-HFO) as a P sink (Freese et al., 1995; Lookman et al., 1995; Bowman et al., 1998).

Thus, several experimental techniques have been used to study soil P desorption behaviour. The simplest procedure is to use a solution which is initially free of P to induce desorption (Kafkafi et al., 1967; Hingston et al., 1974; Barrow, 1979; Reddy et al., 1980; Barrow, 1983). In general, it can be expected that only a very small fraction will be desorbed, until equilibrium with the soil solution is reached. The processes can in principle be repeated to desorb more P. However, experimental (analytical) errors tend to accumulate and only a small percentage of the P present in the sample can be desorbed in this way.

Leaching of soil columns with a P-free solution is another option to study P desorption (Sawhney, 1977; Stuanes and Enfield, 1984; Nagpal, 1986; van der Zee and Gjaltema, 1992). This is an effective method for soils with relatively high P concentrations but not for soils with low P concentrations, due to the strong non-linearity of the phosphate desorption isotherm. Another disadvantage is that the experimental set up required is more complicated and rather expensive. This technique is therefore, not very suitable to study large numbers of soil samples.

Desorption can also be studied by adding materials that bind phosphate strongly, keeping the solution concentration low so that desorption from the soil particles can continue. The added material should have a high capacity to bind P. Another requirement is the possibility of separating the phosphate 'sink' from the soil suspension in order to be able to assess the amount of P desorbed from the soil particles. Anion-exchange resins were originally used for this purpose (Amer et al., 1955; Cooke and Hislop, 1963; Bache and Ireland, 1980; Dalal, 1985; Sayin et al., 1990; Abrams and Jarrell, 1992; Yang and Skogley, 1992).

The resin approach was thought to be more effective when studying the plant available P in the soils, because: (i) anion -exchange resin imitated the general action of plant roots to remove P from the soil solution; (ii) P extracted by anion-exchange resin correlated well with the P absorbed by plants, even when considering soils of quite variable properties (Sibbesen, 1983; van der Zee and van Riemsdijk, 1988). However, the use of anion-exchange resins to desorb P from soil was later found to have some serious drawbacks: (i) the non-specific desorption of different adsorbed anions, (ii) the difficulty in separating the soil from the resin after each desorption step, and (iii) the incapacity of the resin to maintain low P concentrations and to act as an infinite sink (Amer et al., 1955; Barrow and Shaw, 1977; Skogley et al., 1990).

The use of anion-exchange resin membranes proposed by Cooperband and Logan, (1994) provided a major improvement on the point of separability of P sink and soil suspension, however, the disadvantage of using it as a P sink still remained. Apart from the drawbacks mentioned above, the capacity of an anion-exchange resin to extract desorbable P was found to depend on the chemical form of the resin, e.g., Cl^-, HCO_3^-, or OH^- (Sibbesen, 1978; Bache and Ireland, 1980). In practice, however, the bicarbonate form of the resin is the one mainly used, which generally leads to an increase in the pH of the soil suspension, making HPO_4^{2-} species the dominant P ion in soil solution (Abrams and Jarrell, 1992). The use of a strong acid anion-exchange resin for phosphate in a moderately acid pH range of about 5 to 6 is based solely on the fact that a bivalent ion is preferred over monovalent ions in the ion-exchange process. For these reasons, the anion-exchange resin method, although often used to assess plant-available phosphorus, is not ideal for studying P desorption of acid soils (Amer et al., 1955; Cooke and Hislop, 1963; Abrams and Jarrell, 1992; Yang and Skogley, 1992).

To overcome these problems, a method for the assessment of long-term P desorption kinetics of soils using a synthetic ferrihydrite suspension or hydrous ferric oxide (HFO) in dialysis membrane tubes (DMT) as a P sink, has been proposed by Freese et al. (1995). The applicability of dialysis membranes to separate P source and P sink was tested for monophosphate solutions and water extracts of several soils. The system was reported to be mechanically stable for long reaction periods. The pH of the soil solution during desorption remained almost constant. 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. As such, this technique had important advantages over the previous methods. The system was capable of maintaining a constant low P activity in solution, necessary to study long-term P desorption kinetics of soils.

Conventional routine soil P tests

Conventional routine soil tests are used to monitor the phosphate status of soils in terms of plant availability and fertilizer requirements for optimum plant growth. However, these soil tests give only a relative index of available P that can be supplied by the soil for plant growth, but do not measure actual available P quantitatively (Hedley et al., 1982, Tiessen and Moir, 1993). They further contended that, conventional soil tests used to monitor the phosphate status of soil lacks sensitivity. Many tests are designed for routine soil testing making them quick and simple to perform, but they indicate little about the phosphate release rate characteristics of a soil.

According to Tiessen and Moir (1993) it is difficult to describe methods for the determination of soil-available P for two basic reasons: (a) Methods for the determination of available P in an agronomic context never measure the quantity of P available to crop, but measure a pool of soil P that is somehow related to the portion of soil P, which is plant available; (b) P availability needs to be defined with respect to an external sink, i.e. a plant, or plant community (crop). Plants differ in their ability to extract P from soils due to differences in rooting systems, mycorrhizal associations, and growth rates. Since any "immediately available" soil P pool is constantly replenished through reactions of dissolution or desorption of "less available" P, and through the mineralization of organic P, the pool size of "total available" P is strongly time dependent.

Contributions of organic P (P_0) to labile P pools

Previous work by Walker and Syers (1976) and Tiessen et al. (1984), had shown that in highly weathered soils, organic P (P_0) forms may be important in supplying extractable resin inorganic P (P_i). Sharpley (1985) reported that mineralization of P_0 in calcareous and slightly weathered unfertilised soils of the Southern Plains of the U.S.A. could contribute the equivalent of between 10 to 37 kg P ha^{-1} yr^{-1}. The absolute and relative amounts of P_0 mineralised, however, are generally greater for more weathered soils. For example in Ghana, Adepetu and Corey (1976) measured P_0 mineralization rates of 91 and 123 kg P ha^{-1} yr^{-1} for a sandy loam soil under cocoa and a savannah bush respectively. While in Nigeria, Cunningham (1963) found P_0 mineralization rates of 141 to 393 kg P ha^{-1} yr^{-1} for a fine sandy loam soil cleared of tropical rainforest.

Thus, according to Tiessen et al. (1984) the available P was found to be largely controlled by the mineralization of P_o and up to 80 % of the resin extracted P_i has been accounted for by variations in bicarbonate P_o pool in some highly weathered soils. The more stable NaOH extractable P_o pool appeared to act as a sink since most of this P fraction was associated with P that could not be extracted with a resin P_i contents. Moderately labile P_i pools also contribute to the plant available resin P_i but their contribution was only significant in a small number of the cases analysed. However, in a long-term experiment (over 15 years) on Avalon and Clovelly soils in Ermelo, Mpumalanga Province, du Preez and Claassens (1999), found that the NaOH-extractable P (moderately adsorbed P) was mainly responsible for the replenishment of the labile soil P pool. The importance of P_o for plant nutrition in more weathered soils may help to explain observations by Haas et al. (1961) that P_o was reduced by 42 % during 30 to 40 years of cropping in southern U.S. soils but only by 27 % in northern soils.

The analysis of P data based on acceptable concepts of the soil P cycle shows clearly that available P, and therefore the agronomically important P, in highly weathered soils is closely related to the organic P fractions. This may explain the many difficulties encountered in the testing of P fertility in tropical and subtropical soils and indicates that the study of labile forms of P_o might contribute to advances in soil test procedures (Tiessen et al., 1984).

Transformations and distribution of the added P into different soil P pools

Soluble P added to a soil becomes rapidly insoluble. Several possible mechanisms have been proposed to explain P adsorption in acid soils, where the Fe-, Mn-, and Al-P forms are predominant (Hingston et al., 1974; Symith and Sanchez, 1980). Bramley and Barrow (1992) indicated that low pH values encourage reactions between $H_2PO_2^-$ and Fe, Al, Mn, and silicate minerals. While at neutral to high pH values both the $H_2PO_4^-$ and HPO_4^{-2} ions would be found and the main reaction for P fixation would be as calcium phosphate ($Ca_3(PO_4)_2$) (Brady, 1990; Doula et al., 1996). In calcareous soils, solid phase $CaCO_3$ is believed to govern P reactions.

However, the reactivity of $CaCO_3$ is dependent on specific surface that is related to particle size distribution, rather than to total $CaCO_3$ (Holford and Mattingly, 1975).

The organic matter on the other hand form complexes with Fe, Al ions, and the oxihydroxides thereby preventing these materials from reacting with applied fertilizer P. Several workers have noted positive correlations between soil organic matter and P adsorption capacity. However, according to Doula et al. (1996) it seems more likely that this is indicative of soils with adsorption sites suitable for both P and organic anions, rather than of adsorption of P by the organic matter. Thus, P held in organic form can occur under appropriate conditions, be released into the soil solution, and then become subject to uptake by plants or fixed into some insoluble form (Doula et al., 1996).

Bramley and Barrow (1992) reported that as the initially added P concentration increased, the percentage of P sorped decreased. They explained that at low P concentration, available and easily reached sorption sites are immediately occupied, while at higher P concentrations, the more difficult sorption sites are also reached but the percentage P complexed become less as the sites become occupied.

The effects of incubation on desorption rates of applied P from different P pools

In a study to find a more general method for describing P desorption that was applicable after both short and long periods of contact between soil and P prior to desorption, Barrow (1979) found that after short periods of incubation (1 hour-20 days), the amount of P desorbed in dilute $CaCl_2$ solutions increased rapidly at first but then net re-adsorption occurred. After long periods of incubation (62-240 days), desorption was slower and there was no net re-adsorption.

Mckean and Warren (1996) found that time and temperature of incubation affected the amount of added P that can be recovered both at first extraction and the ultimate amount. In different soils, there were different responses to the incubation treatments. By comparing the different incubation times and temperatures, the initial amount of P recovered by successive resin extractions was found to decrease with an increase in either time or temperature of incubation. This was in agreement with the work of Barrow and Shaw (1975b), who reported that the ultimate amount of P that could be recovered was almost always less than or little different from the amount of P added. Where recovery was in excess of 100 %, a possible explanation was that the addition of inorganic P caused an increase in the mineralization of organic P as reported by Dalal (1977). Increasing incubation time from 2–55 days generally lowered the ultimate amount of P that could be recovered, suggesting that after incubation for a long time, the slow P adsorption reaction had reduced the amount of readily desorbable P (Barrow and Shaw, 1975c).

Determinations of the residual effects of applied fertilizer P

The rate of P sorption by soils is initially fast and then continues slowly for a long time with no apparent end (Amer et al., 1955; Munns and Fox, 1976; Bramley and Barrow, 1992; Mckean and Warren, 1996). Barrow and Shaw (1975a) described the P adsorption and desorption reactions using a three compartment model: A $\leftarrow\rightarrow$ B $\leftarrow\rightarrow$ C. Compartment A represented the phosphate in the soil solution, the equilibrium between A and B was rapid and this reaction determined the initial adsorption of added phosphate, and therefore, its initial effectiveness. The transfer of phosphate between compartments B and C was slower and the phosphate was held more firmly in compartment C. The extent to which this slow adsorption reaction was then reversible (desorption) was fundamental in determining the residual effectiveness of added P (Barrow and Shaw, 1975b).

Mckean and Warren (1996) using successive resin extractions showed differences between treatments that were similar in the initial amounts of added P. In some soils, the desorption curves reached a plateau by the eighth extraction or before where no more P could be recovered, while others continued to release P slowly. This property could be relevant for the crop in the field with respect to the residual effect of added fertilizer P. Thus a knowledge of the type of desorption curve that the soil has, i.e.

whether it reaches a plateau or whether it continues to release phosphate could be important in the economical management of fertilizer applications.

The amount of available soil P has been more frequently evaluated than the rate of its release when studying the P nutrition of plants. The availability of a nutrient to plants depends, among others, on the rate at which it is released to replenish the soil solution (Amer et al., 1955; Cooke, 1966; Williams et al., 1967; Barber, 1984). Dalal and Hallsworth (1976) reported that the rate of soil P release to anion-exchange resin could be correlated with P uptake at relatively early plant growth stages. Parameters related to the P desorption kinetics from soils, such as calculated rate constants, have shown significant correlation with plant uptake (Cooke, 1966; Onken and Matheson, 1982). However, these relationships are difficult to interpret since the rate constant of each kinetic model has a unique characteristic (Raven and Hossner, 1994).

The residual plant-available P in soils could also be quantified by successive cropping experiments carried out in field or greenhouse conditions. In such experiments, plant-available P is removed until P deficiency occurs or a response to added P is measured (Mckean and Warren, 1996; du Preez and Claassens, 1999; Kamprath, 1999). This approach, however, is very expensive and time consuming, and methods that approximate a biological measure could represent very useful analytical tools in P fertility and effectiveness of P fertilizer in soils (Indiati, 1998).

Use of successive DMT-HFO-P extractions to simulate mechanism of P sorption by plant roots

The soil test methods that have limited effects on the soil system are isotopic exchange techniques (Amer et al., 1955); anion-exchange resins (Amer et al., 1955; Hedley et al., 1982; Dalal, 1985; van Raij et al., 1986); iron oxide-impregnated paper strips (Menon et al., 1990; Tiessen and Moir, 1993); and DMT-HFO (Freese et al., 1995; Lookman et al., 1995). These methods extract more of the "available P" than the chemical procedures. They estimate the labile P pools and are good indicators of plant available P, more closely reflecting processes involved in P uptake by plant roots in soil. In fact, resin, Fe oxide-coated paper strips, and DMT-HFO serve as a sink for released P, preventing solution P built up to levels where further P release is inhibited.

The applicability of dialysis membranes to separate P source and P sink was tested for monophosphate solutions and water extracts of several soils. The system was reported to be mechanically stable for long reaction periods (Freese et al., 1995; Lookman et al., 1995). The pH of the soil solution during desorption remained almost constant. 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. As such, this technique had important advantages over the resin, and Fe oxide-coated paper strips, methods. The system was capable of maintaining a constant low P activity in solution, necessary to study long-term P desorption kinetics of soils. Successive extractions carried out by this method may constitute a convenient laboratory method to characterize the capacity of soil to supply P, and to investigate the rates of P release from original and P fertilized soils ((Freese et al., 1995; Lookman et al., 1995); Indiati, 1998).

The research objectives were:

(1) To study the transformations and distribution of the initial and the added P into the different P pools by use of the successive DMT-HFO and the sequential P extractions, after different incubation periods;

(2) How added P changed the equilibrium between the different P pools and the desorption rates of P after incubation periods; and

(3) To determine which P pools were supplying the P to the successive DMT-HFO-P extractions and at what rates.

It was hypothesized:

(1) That the initial and applied fertilizer P are adsorbed or fixed to varied degrees by the Hutton soils of Rustenburg and Loskop experimental

farms and thus become unavailable to plants;

(2) That the fate of the applied fertilizer P may be predicted by the use of sequential P fractionation procedures to determine the P adsorption and desorption characteristics of these soils;

(3) That the sequential P fractionation procedures could be used to determine some transformations in the initial and applied P and the distribution of P within the different P pools of the two soils during the incubation periods.

(4) That by successive P extractions using the DMT-HFO procedure it is possible to simulate P absorption by plant roots;

(5) That it is possible to determine the release rates of the adsorbed or fixed P, over time by successive extractions of plant-available P and the sequential P extractions to determine the P pool supplying the labile P.

CHAPTER 2

A STUDY ON THE CHANGES AND DISTRIBUTION OF THE INITIAL AND APPLIED P INTO THE DIFFERENT P POOLS IN HIGH AND LOW P FIXING SOILS AFTER DIFFERENT INCUBATION PERIODS

INTRODUCTION

Phosphorus deficiency in plants is believed to constitute the second most important soil fertility problem throughout the world (Lindsay et al., 1989). Sattell and Morris (1992) stated that phosphorus was the second most limiting element in the Alfisols of tropical Asia, Africa, and South America. The acquisition of precise information concerning soil phosphate availability is a prerequisite to ensure sustainable management of soil. Thus, the characterization of soil phosphate availability has been the focus of numerous studies.

The P fractionation procedure to characterize different inorganic P fractions in fertility studies was used by Chang and Jackson (1957). The progressive importance given to the organic P fraction made it necessary to look for more comprehensive fractionation procedures like that proposed by Hedley et al. (1982). This procedure has been used in different soils to study the transformations and distribution of inorganic and organic P forms (Vazquez et al., 1991). Tiessen and Moir (1993) regrouped the P fractions based on the rates of their renovations or transformations into the different P pools. This allowed for the development of a more dynamic picture of P transformations in the soils.

The overall advantage of the fractionation of soil P into the different P categories is that it permits the determination of the chemical status of the residual and applied P. Thus, Hedley et al. (1982) reported that the sequential fractionation procedure they proposed could be used to record changes in soil P that occur during short-term incubation experiments.

Recently, a methodology for the assessment of long-term P desorption kinetics of soils using hydrous ferric oxide in dialysis membrane tubes (DMT-HFO) as a P sink, was proposed (Freese et al., 1995). The ability of dialysis membrane tubes (DMT) to separate the P source in the soil and the P sink (HFO in the DMT tube) was tested for phosphate solutions and water extracts of several soils. The system was reported to be mechanically stable for long reaction periods, while the pH of the soil solution during desorption remained almost constant. After the desired time of contact between the soil suspension and P sink, the sink could easily be separated from the soil suspension with practically no loss of soil material. This new technique has thus important advantages over the previously used resin methods. The system was capable of maintaining a constant low P activity in solution, necessary to study long-term P desorption kinetics of soils for over 500 hours.

Soils of Rustenburg and Loskop experimental farms with high and low P fixing capacities respectively

(a) Rustenburg soil

The soils of the formerly Tobacco and Cotton Research Institute (ARC-TCRI) now renamed ARC-Institute for Industrial Crops (ARC–IIC), at Rustenburg were previously surveyed by Botha et al. (1968), and five different soil types were identified. The "dark reddish brown sandy clay soils", classified as Hutton form, and Ventersdop family according to the Soil Classification Working Group (1991) was selected for this research. This is equivalent to Ferric Luvisols of the FAO/UNESCO System (1974), or Alfisols (Haplo-Palcustalfs) of the USDA System (1975). It is a structure-less, deep red soil, and varies considerably in texture. The clay fraction was found to contain mainly kaolinitic clays (52 %). The soil has a relatively high water holding capacity due to its high fine sand and clay contents. Chemical analysis showed medium to high N, low to medium organic carbon, and low plant available P, and a pH near neutrality (6.0-7.2) (Table 1).

Some trials carried out on this soil reportedly showed a high P fixing capacity. Crops tested especially tobacco showed severe P deficiency symptoms. Several trails to correct the deficiency by applications of different sources of P (e.g. triple super phosphates, single super phosphates, mono-ammonium and di-ammonium P), liming, and incorporations of mycorrhiza failed to produce satisfactory results. The trials with cotton also showed clear signs of P deficiencies (i.e. stunted growth, smallish dark leaves, low boll survival rates, and the characteristic leaf reddening symptoms of late-season P deficiency).

(b) Loskop soils

A similar soil type was identified at Loskop experimental farm near Groblersdal. The soil was identified as “dark reddish brown sandy loam” (Botha et al., 1968). It also falls under the Hutton form but to the Shorrocks family. This is equivalent to Ferric Acrisols (FAO/UNESCO System, 1974) or Alfisols (Pale-Xerults) (USDA System, 1975). Its chemical, mineralogical, and physical data are also shown in Table 1. However, the Loskop soil shows only low to moderate P sorption capacities.

It was therefore hypothesized that the added fertilizer P in both soils could be adsorbed to varied degrees by Al- and Fe- oxihydroxides, soil organic matter, and layered silicate clay crystals, or precipitated as Ca and Mg compounds depending on the pH that ranges near neutrality. Due to the limited P uptake in the Rustenburg soil by both the tobacco and cotton plants, it was found necessary to investigate the fate of both the initial and the applied P in the high P fixing Rustenburg and the low P fixing Loskop soils by use of the sequential P fractionation procedures after different P treatments and incubation experiments.

MATERIALS AND METHODS

1: MATERIALS

1.1: Soils

The soils for this research were obtained from ARC – Institute for Industrial Crops, Rustenburg and the affiliated experimental station at Loskop near Groblersdal. These areas are situated at 25.7 ^{0}S / 27.3 ^{0}E (North West Province), and 25.2 ^{0}S / 29.4 ^{0}E (Mpumalanga Province) respectively, in the Republic of South Africa. These two soils (Rustenburg and Lokop) have already been described in details on pages 19 and 20.

1.2: Incubation materials

- -1 000 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 samples

Soils from Rustenburg and Loskop were used in the trials. Bulk samples of 200 kg each were collected from the fields. Both soils have been under cropping for the last 5 years, and fertilized as recommended for different crops. 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 then thoroughly mixed and stored at room temperature.

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2.2: P-Treatments

Potassium dihydrogen phosphate (KH_2PO_4) was used as the P source. The calculated values equivalent to 0, 5, 10, 20, 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 mg P kg^{-1} were weighed out and made up as stock solutions. To each 500 g soil sample weighed out into a 1 000 cm^3 glass jar, the calculated volume of the stock solution was added, mixed thoroughly with the soil, and brought to field capacity before starting the incubation processes.

2.3: Incubation

Five (5) incubation periods (1, 60, 120, 180, and 240 days) were applied on each P treatment. Each treatment combination was then replicated three times. The samples were put in boxes and placed randomly in a climatic room where they were incubated at a temperature of 20 ^{0}C (+ or - 2 ^{0}C). After each incubation period, the replicated samples of each P treatment were withdrawn and forced air dried before they were used for the sequential P extractions.

3: SOIL ANALYSES

3.1: Routine chemical, physical, and mineralogical analyses

Before commencing the incubation treatments, each soil was selectively analysed for pH, N, organic carbon (O.C.), P (Bray 1 and 2), Total P, exchangeable K, Ca, Mg, texture and clay mineralogy according to Black et al. (1965) methods.

3.2: Sequential P extractions

The sequential P extractions were carried out as described by Tiessen and Moir (1993) with one modification. The resin strips were replaced by dialysis membrane tubes filled with hydrous ferric oxide (DMT-HFO), as described by Freese et al. (1995).

3.2.1: Materials

- pH metre
- Horizontal shaker
- Centrifuge
- Spectrophotometer
- Water bath
- Digestion rack
- DMT- Dialysis membrane tube strips
- Medi - clips (clips)
- Extran, - phosphate free washing reagent
- **HCl**: Conc (11.3M), 0.5M, and 1.0M
- 0.5M $NaHCO_3$
- **NaOH**: 4M, 1M, and 0.1M
- **H_2O_2**: 30%
- **H_2SO_4**: Conc (18M), 2.5M, 0.9M, and 0.25M

- **Ammonium molybdate**: Dissolve 40.0 g in 1000 cm^3 of deionized water.
- **Ascorbic acid**: Dissolve 26.4 g in 500 cm^3 of deionized water.
- **Antimony potassium tartrate**: Dissolve 1.454 g in 500 cm^3 of deionized water.

- **Solution A**: Add 75 cm^3 ammonium molybdate, 50 cm^3 ascorbic acid and 25 cm^3 of antimony potassium tartrate solutions to 250 cm^3 of 2.5M H_2SO_4, and dilute to a final volume of 500 cm^3 with deionized water in a volumetric flask.

- **Hydrous ferric oxide (HFO) suspension**: Dissolve 200 g of ferric nitrate nonahydrate in 2 000 cm^3 of deionized water. Add drop wise 1M NaOH until a pH of 7 to 8 is obtained. The suspension is then centrifuged for 10 minutes, decanted, and re-suspended in deionized water. This procedure is repeated at least two times. Finally, the hydrous ferric oxide (HFO) is suspended in deionized water to obtain a volume of 4 000 cm^3 and adjusted with 0.5M HCl to pH 6.5 (i.e. close to the pH of the soils under study). This suspension is stable for two weeks.

-Dialysis membrane tubes (DMT): Fifteen cm-lengths of the dialysis membrane tubes (DMT) are boiled twice in deionised water for 5 minutes at a time. After each boiling period the tubes are rinsed thoroughly. Each dialysis tube is then closed at one end with a clip and filled with 10 cm^3 of HFO suspension (approximately 0.05M Fe per DMT tube), and the open end also closed with a clip. While filling the tubes, the HFO suspension is stirred vigorously to obtain a homogeneous suspension.

3.2.2: P determinations by Murphy - Riley (1962) method

This method is used to determine directly the P extracted from the DMT-HFO, the dilute and concentrated HCl, and the conc. $H_2SO_4 + H_2O_2$ extracts.

Pipette 10 cm^3 aliquot into a 100 cm^3 volumetric flask. Add two drops of the paranitrophenol as an indicator and adjust the pH. If the extract is too acidic, adjust the pH with 4M NaOH to yellow and then with 0.25 M H_2SO_4 until the indicator just turns clear. For alkaline extracts just acidify.

Add 8 cm^3 of Solution A, fill up to the volume, shake, and read on the spectrophotometer at 772 nm after 10 minutes (colour is stable for 24 hours).

3.2.3: Determination of the inorganic P (P_i) in the dilute and conc. HCl (D/HCl-P_i and C/HCl-P_i) and $H_2SO_4 + H_2O_2$ (H_2SO_4-P_i) extracts

Pipette 10 cm^3 aliquot into a 100 cm^3 volumetric flask and determine the P according to Murphy–Riley (1962) method.

3.2.4: Determination of the inorganic P in the 0.5M $NaHCO_3$ (-HCO_3-P_i) and 0.1M NaOH (-OH-P_i) extracts

- Pipette 10 cm^3 of the extract into a 50 cm^3 centrifuge tube.
- Acidify the 0.5M $NaHCO_3$ extract by adding 6 cm^3 of the 0.9M H_2SO_4 solution and the 0.1M NaOH extracts with 1.6 cm^3 of the same solution, and then cool them down in a cold room for 30 minutes.
- Centrifuge at 2 500 RPM for 10 minutes.
- Decant the supernatant into a 100 cm^3 volumetric flask.
- Rinse the tubes carefully (without disturbing the precipitated organic material) with 2–3 cm^3 of acidified water.
- Adjust the pH and measure the P content as described in (3.2.2).

3.2.5: Determination of the total P in the 0.5M $NaHCO_3$ (-HCO_3-P_t), 0.1M NaOH (-OH-P_t), and conc. HCl (C/HCl-P_t) extracts

- Pipette 5 cm^3 of the extract into 100 cm^3 volumetric flasks.
- To the 0.5M $NaHCO_3$ extract add 0.5 g ammonium persulfate and 10 cm^3 0.9M H_2SO_4.
- To the 0.1M NaOH extract add 0.6 g ammonium persulfate and 10 cm^3 0.9M H_2SO_4.
- To the conc. HCl extract add 0.4 g ammonium persulfate and 10 cm^3 deionized water.
- Cover with tin foil (double layer for conc. HCl) and heat very slowly on a hot plate, the $NaHCO_3$ and HCl extracts for 60 minutes, and the NaOH extract for 90 minutes.
- Adjust the pH and measure the P content as described in Section 3.2.2.

3.2.6: Procedures for the P sequential extractions

Day 1: Weigh out 1.00 g of soil into 100 cm^3 polyethylene flasks. Add 80 cm^3 of a solution containing 0.002 M $CaCl_2$ and 0.0003 M KCl.

Place the 15 cm DMT tubes filled with 10 cm^3 HFO in the soil suspension and shake gently for 16 hours.

Day 2: Prior to removing the DMT-HFO tube, the soil material adhering to it is rubbed off with a glass rod to minimize loss of soil material from the suspension and then rinsed with deionized water to remove any remaining traces of adhering soil material. The DMT-HFO tube is then transferred to a conical flask where it is opened and 1 cm^3 of conc. H_2SO_4 is added to the extract to dissolve the HFO before the empty DMT is removed. Determine the DMT-HFO-P_i as described in Section 3.2.2.

Centrifuge the soil suspension at 2 500 RPM for 10 minutes, filter through millipore filter (pore size 0.45μm) and then wash the soil from the filter back into the centrifuge tube with 30 cm^3 of 0.5M $NaHCO_3$ solution and then shake the suspension overnight (16 hours). Ensure that all the soil is in suspension before starting to shake.

Day 3: Centrifuge the soil suspension at 2 500 RPM for 10 minutes. Filter the $NaHCO_3$ extract through a millipore filter into a 50 cm^3 volumetric flask. Determine the inorganic P_i (HCO_3-P_i) and total P_t (HCO_3-P_t) on the bicarbonate extract as described in sections 3.2.4 and 3.2.5 respectively. Wash all the soil from the filter back into the tube with 30 cm^3 0.1M NaOH and shake the suspension overnight.

Day 4: Centrifuge the suspension at 2 500 RPM for 10 minutes. Decant the NaOH extract through a millipore filter into a 50 cm^3 volumetric flask. Determine inorganic P_i (OH-P_i) and total P_t (OH-P_t) in the NaOH extract as described in Sections 3.2.4 and 3.2.5 respectively. Wash all the soil from the filter back into the tube with 30 cm^3 of 1M HCl and shake the suspension overnight.

Day 5: Centrifuge the soil suspension at 2 500 RPM for 10 minutes. Decant the HCl extract through a millipore filter into a 50 cm^3 volumetric flask. Determine the inorganic P (HCl-P_i) in the HCl extract.

Wash the soil from the filter back into the centrifuge tube with 10 cm^3 conc. HCl. Heat the soil sample on a water bath at 80°C for 10 minutes. Suspend the soil sample in the HCl by vortex before heating the suspension for approximately 10 minutes to come to temperature, add a further 5 cm^3 conc. HCl, vortex, and let it stay at room temperature for 1 hour (vortex every 15 minutes). Centrifuge at 2 500 RPM for 10 minutes and decant supernatant into a 100 cm^3 volumetric flask. Wash the soil with 10 cm^3 H_2O and centrifuge. Add the supernatant together with the test solution, make to 100 cm^3, and determine the inorganic P_i (HCl-P_i) and total P_t (HCl-P_t) in HCl solution as described in Sections 3.2.4 and 3.2.5 respectively.

Add 10 cm^3 of deionized water to the soil residue and vortex to disperse the soil. Transfer the suspension into a 75 cm^3 digestion tubes (use the minimum amount of water possible to transfer all the soil residue), add 5 cm^3 conc. H_2SO_4 and one boiling chip (Hengar granules), vortex, and put on a cold digestion block. Raise the temperature very slowly to evaporate water and when 360 °C is reached H_2O_2 is added as follows: remove the tubes from the digestion block and let them cool to hand-warm; add 0.5 cm^3 of H_2O_2; reheat for 30 minutes to evaporate H_2O_2. Repeat the H_2O_2 additions until the liquid is clear (usually about 5 - 10 times to decompose the H_2O_2). Make sure there is adequate heating after the final H_2O_2 addition, since residual H_2O_2 interferes with the P determination. Cool, make up to volume, shake, and allow residue to settle out overnight. Determine P_i (H_2SO_4-P_i) in the extracted solution according to the Murphy- Riley (1962) method.

3.2.4: P–standards

The P concentrations were determined according to the method of Murphy-Riley (1962). The concentrations were determined by comparing the colour developed with a standard range. The standard solutions for the different P extractions were prepared with the same extraction reagent and concentrations as in the unknown sample solutions.

A standard stock solution containing 250 mg P dm^{-3} was prepared by weighing accurately 1.0982 gm of oven-dry Analar KH_2PO_4 into a clean $1dm^3$ volumetric flask, dissolved in deionised water and then filled to the mark.

A standard range was prepared by pipetting into 11 clean 100 cm^3 volumetric flasks, 0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 cm^3 of the stock solution. An equal amount of one of the extracting solutions (e.g. $NaHCO_3$) was added to each of the volumetric flasks and then 8 cm^3 of the colour reagent was added and filled up to the mark with deionised water

After the colour had developed for 1 hour, the blue colour intensities of the solutions were determined by a spectrophotometer, at a wavelength of 772 nm. The P concentrations of the extracts were then read off from the standard P curves.

Procedure	P - Fractions/Functional roles
1.0 g soil	
↓	
Extraction with DMT-HFO in water	soluble - available P_i
↓	
Extraction with 0.5M $NaHCO_3$	labile - P_i and P_o
↓	
Extraction with 0.1M NaOH	Al-, Fe-hydrous oxide bound-P slow - labile - P_i and P_o
↓	
Extraction with dil. 1.0M HCl	Ca - bound - P slow - labile - P_i
↓	
Extraction with conc. HCl	occluded/recalcitrant - P fixed/unavailable P_i and P_o
↓	
Extraction with conc.$H_2SO_4 + H_2O_2$	residual/recalcitrant/lattice - P fixed/unavailable P_i and P_o

Fig. 1: Flow chart of the sequential P extractions

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 F values were statistically different between or among the treatments. The Least Significant Differences (LSDs) were determined by the LSD Fisher tests at 5% confidence level. The correlation coefficients were determined as well as the regression equations for the exponential fits of the graphs.

The graphs for the extracted P and percent P recovered are presented as smooth curves constructed through different regression fits using 'Microsoft Excel' (1995) programmes: Where linear: $y = mx + b$ (where m is the slope and b is the intercept); logarithmic: $y = c\,ln x + b$ (where c and b are constants, and ln is the natural logarithm function); polynomial: $y = b + c_1x + c_2x^2$ (where b, c_1 and c_2 are constants); exponential $y = ce^{bx}$ (where c and b are constants, and e is the natural logarithm; and power: $y = cx^b$ (where c and b are constants) to produce the best fits for each set of data. The graphs are accompanied by regression equations and the correlation coefficient (R^2) values.

To calculate the percentage recovery of the added P the amount of the initial soil P extracted was subtracted from the amount recovered after incubation under the same conditions with the added P, thereby correcting for the effect of the initial P during incubation. Thus % P recovered = $(Px–Po)/P1*100$; where P*x* was P in the *x*th fraction of the P treatment, and P*o* was P in the *o*th fraction of the initial no P (P0) treatment, while P1 was the applied P level (Sattell and Morris, 1992; Doula et al., 1996).

RESULTS AND DISCUSSION

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

Some selected properties of the two soils (Table 1) under study show that the Rustenburg soil is a sandy-clay while the Loskop soil is a sandy-loam. Kaolinite is the dominant clay mineral in both soils. The pH (H_2O: 1:2.5 suspension) values show that the soils are near neutral. The organic carbon content is low for both soils although it is a little bit higher in the Rustenburg soil (Black et al., 1965). Initial P contents (Bray 1) were generally low for both soils. According to Sharpley (1996), Bray 1 gave the best indications of labile P in the slightly to highly weathered soils.

2. Sequential fractionations of soil P into various inorganic-P (P_i), and organic-P (P_o) pools

The sequential P extractions were carried out as outlined by Tiessen and Moir (1993) with a slight modification, where the resin strips were replaced by dialysis membrane tubes filled with hydrous ferric oxides (DMT-HFO), as described by Freese et al., (1995). The procedures used are summarized in the flow chart in Figure 1.

The summaries of the results of the sequentially extracted P and percent P recoveries of the added P as influenced by added P and incubation periods are presented in Tables 2-3.

Table 1: Some chemical, physical, and mineralogical characteristics of Rustenburg (R) and Loskop (L) soils

Soil Samples Depths (cm)	R 30	R 60	R 90	L 30	L 60
Soil Texture (%)					
Sand	42	38	34	81	72
Silt	7	7	9	0	1
Clay	51	55	57	19	27
Textural Class	Sandy-clay	Clay	Clay	Sandy-loam	Sandy clay-loam
Clay Mineralogy (%)					
Kaolinite	52	54	40	37	26
Quartz	29	35	18	52	74
pH H_2O (1:2.5)	6.87	6.82	6.60	6.84	6.47
Total N (mg kg^{-1})	486	419	347	206	163
O.C. ,,	6700	5800	4400	4100	3900
P (Bray 1) ,,	5.0	3.0	0.0	12.5	1.0
P (Bray 2) ,,	8.0	4.5	0.5	16.5	1.0
Total P ,,	265.0	202.0	95.8	152.8	97.5
K ,,	250	178	83	198	100
Ca ,,	910	853	690	640	720
Mg ,,	683	720	830	200	240

Tables 4-8 show the transformations and distribution of the sequentially extracted-P fractions with the various rates of added P and incubation period as percentages of the total soil P pools for Rustenburg and Loskop soils. Figures 2-10 show the regression equation curves. The analyses of variances (ANOVA) and the tables of means are presented in Appendices I Nos. 1-24. In general the ANOVA tables show that there were highly significant changes ($P = 0.01$) in the sequentially extracted-P fractions with all the rates of the added P, the incubation period, and their interactions (Rustenburg, Appendices I Nos. 1-12; Loskop, Appendices I Nos. 13-24). Figures 2-10 present the regression equations with the best-fitted linear, exponential, logarithmic, polynomial, and power functions. The R^2 values indicated very good correlations in most cases.

3. The effects of P and incubation treatments on the sequentially extracted inorganic P (P_i), organic P (P_o), percentage P recovered, and P distribution into different P pools

According to their relative availabilities to plants in the soils, the results of the sequentially extracted P have been classified into three groups:

(a) Plant-available P: comprising solution or freely available P (DMT–HFO-P_i extracts) and labile P (0.5M $NaHCO_3$-P_i and P_o);

(b) Adsorbed P: consisting of adsorbed or slow labile P (0.1M NaOH-P_i plus P_o, and 1.0M HCl-P_i extracts);

(c) Occluded and residual P: consisting of occluded and recalcitrant P (conc. HCl-P_i and P_o extracts), and residual, fixed or lattice P (conc. H_2SO_4 + H_2O_2-P_i and P_o extracts);

The organic P (P_o) that falls within each group is regarded as having comparable availabilities to the P_i (Hedley et al., 1982; Tiessen and Moir, 1993).

3a: The effects of the added P and incubation time on the extractable plant-available P - [solution P (DMT-HFO-P_i) and labile P (0.5M $NaHCO_3$-P_i and P_o)]

3a: (i). The effects of the added P and the incubation period on DMT-HFO-P_i

The results of the extractable and percent recoveries of the added P are presented in Tables 2-3. While Figures 2a and b show the regression curves. The analyses of variances (ANOVA) and the tables of means are presented in Appendices I Nos. 1 and 13 respectively for Rustenburg and Loskop soils. The ANOVA tables showed highly significant differences ($P = 0.01$) in the DMT-HFO extracted-P fraction with the levels of added P, incubation periods, and their interactions in both soils. The data in Tables 2-3 shows that, the extracted DMT-HFO-P_i fraction increased with increasing levels of the added P. However, the amounts extracted for each level of added P decreased with increasing incubation time. This would tend to agree with Doula et al. (1996), who reported that soluble P added to a soil is usually adsorbed and precipitated rapidly but the concentrations in solution continue to decline slowly over a period of months.

The DMT-HFO-P_i extracts of Rustenburg soil were low and ranged from 2.50-40.09 mg kg^{-1} after 1 day to only 2.79-12.59 mg kg^{-1} after 240 days of incubation from 0-200 mg kg^{-1} of applied P. This represented percent P recoveries of 28.92-18.80 % after 1 day to only 7.36-4.90 % after 240 days from the lowest and the highest added P respectively (Table 2). According to Freese et al. (1995), this is well below the capacity of the DMT to diffuse P across the membrane in 16 hours. Tables 4a and 8a showed that the DMT-HFO-P_i extracted only a small fraction of the total soil P pool. The proportion varied from 1.35-10.75 % after one day to only 1.31-3.00 % after 240 days.

The corresponding values for Loskop soil showed the same trend but differed in that more P was extracted than from the Rustenburg soil. Table 3 shows that the values varied from 5.40–64.78 (1 day) to 4.54-16.75 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} added P. These represent percent P recoveries of 21.08-29.69 % (1 day) and 7.68-6.11 % (240 days) from 25-200 mg kg^{-1} added P respectively. The proportion of the DMT-HFO extracted P_i after 16 hours extraction time also constituted only a small fraction of the total soil P pool, although relatively higher than for the Rustenburg soil. They ranged from 3.83-19.50 % (1 day) and 2.83-4.65 % after 240 days of incubation with 25-200 mg kg^{-1} added P respectively (Tables 4b-8b).

Figures 2a and b show the effects of the applied P and the incubation periods on the DMT-HFO-P_i extracts from (a) Rustenburg and (b) Loskop soils respectively between 1 and 240 days of incubation. The graphs show that for both soils DMT-HFO- extracted P_i increased with the increasing P levels, but were greatly reduced by the number of days they were under incubation. Thus, increasing incubation period from 1-240 days reduced the amount of P_i that can be extracted with DMT-HFO significantly suggesting that during the incubation processes the slow adsorption reaction reduces the amounts of the solution (DMT-HFO-P_i) phosphates (Doula et al., 1996).

Rustenburg soil shows a big difference in extractable P between 1 day and 60 days, where after only limited DMT-HFO-P_i remained available for extraction. It should be noted that the greater the distances between the lines of the fitted curves of the labile P (DMT-HFO- and –HCO_3-P extracts), the greater the P-fixation capacity of the soil and the shorter the time it takes to fix the added P (e.g. 1 day vis-à-vis 60 days in Figs. 2 and 3) (Sattell and Morris, 1992; Doula et al., 1996).

In contrast, the Loskop soil took longer to reach equilibrium because it was only after 120 days that the distances between the lines became small indicating little fixation thereafter. In general more DMT-HFO-P_i was extracted from Loskop than from Rustenburg soil from all the added P levels throughout the incubation period, indicating that the Rustenburg soil has the capacity to fix P faster than the Loskop soil. However, after 120 days both soils were able to equally fix most of the applied P because the percentages recovered after longer periods of incubation were relatively low and more or less the same.

Table 2: The effects of the added P and incubation period on the sequentially extracted inorganic P, organic P, and percent P recovered from Rustenburg soil.

Incubation period (days)	1							60							120						
Added P (mg kg^{-1})	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P
HFO-P_i	2.50	9.73	17.10	30.59	33.12	40.09	22.19	2.87	6.08	6.92	12.00	16.92	19.58	10.73	2.75	5.65	6.17	9.17	13.23	15.17	8.69
% P recovered		28.92	29.20	28.09	20.41	18.80	25.08		12.84	8.10	9.13	9.37	8.36	9.56		11.60	6.84	6.42	6.99	6.21	7.61
HCO_3-P_i	6.30	17.42	25.99	32.00	41.89	67.13	31.79	6.00	7.58	13.75	18.08	24.08	31.25	16.79	4.20	5.17	8.08	12.50	20.33	23.58	12.31
% P recovered		44.48	39.38	25.70	23.73	30.42	32.74		6.32	15.50	12.08	12.05	12.63	11.72		3.88	7.76	8.30	10.75	9.69	8.08
OH-P_i	30.00	35.80	39.37	61.03	68.20	82.53	52.82	34.33	42.00	52.08	68.33	83.67	94.42	62.47	43.42	48.25	54.17	72.00	85.25	98.00	66.85
% P recovered		23.20	18.74	31.03	25.47	26.27	24.94		30.68	35.50	34.00	32.89	30.05	32.62		19.32	21.50	28.58	27.89	27.29	24.92
D/HCl-P_i	6.73	7.14	9.76	13.40	14.05	15.07	11.03	6.92	9.42	12.33	15.08	17.58	19.92	13.54	7.25	10.17	13.21	16.08	18.92	22.04	14.61
% P recovered		1.64	6.06	6.67	4.88	4.17	4.68		10.00	10.82	8.16	7.11	6.50	8.52		11.68	11.92	8.83	7.78	7.40	9.52
C/HCl-P_i	50.93	51.60	53.83	56.93	60.97	63.73	56.33	58.00	60.00	62.33	65.67	70.33	75.33	65.28	58.33	61.33	65.00	76.00	80.67	93.00	72.39
% P recovered		2.68	5.80	6.00	6.69	6.40	5.51		8.00	8.66	7.67	8.22	8.67	8.24		12.00	13.34	17.67	14.89	17.34	15.05
$H_2SO_4P_i$	55.27	56.17	56.83	57.33	59.50	61.67	57.80	55.73	56.67	59.00	65.22	72.38	80.47	64.91	56.50	58.83	65.67	74.17	80.17	89.50	70.81
% P recovered		3.60	3.12	2.06	2.82	3.20	2.96		3.76	6.54	9.49	11.10	12.37	8.65		9.32	18.34	17.67	15.78	16.50	15.52
HCO_3-P_o	10.00	10.47	10.72	11.37	11.77	12.90	11.21	10.00	14.75	18.17	22.67	24.00	26.17	19.29	11.00	15.00	17.67	19.33	21.50	23.00	17.92
% P recovered		1.88	1.44	1.37	1.18	1.45	1.46		19.00	16.34	12.67	9.33	8.09	13.09		16.00	13.34	8.33	7.00	6.00	10.13
OH-P_o	13.80	14.47	14.97	15.10	15.90	15.97	15.04	14.17	16.34	20.63	24.25	25.92	26.79	21.35	15.21	17.25	22.33	25.58	26.88	28.08	22.56
% P recovered		2.68	2.34	1.30	1.40	1.09	1.76		8.68	12.92	10.08	7.83	6.31	9.16		8.16	14.24	10.37	7.78	6.44	9.40
C/HCl-P_o	9.67	9.73	10.10	10.50	13.65	13.80	11.24	11.75	12.17	13.50	16.25	17.93	19.25	15.14	12.83	13.17	15.00	18.50	19.00	20.67	16.53
% P recovered		0.24	0.86	0.83	2.65	2.07	1.33		1.68	3.50	4.50	4.12	3.75	3.51		1.36	4.34	5.67	4.11	3.92	3.88
Total P extracted	185.20	212.53	238.67	288.25	319.05	372.89	269.43	199.77	225.01	258.71	307.55	352.81	393.18	289.51	211.49	234.82	267.30	323.33	365.95	413.04	302.66
Total % P recovered		109.32	106.94	103.05	89.23	93.85	100.48		100.96	117.88	107.78	102.03	96.71	105.07		93.32	111.62	111.84	102.97	100.78	104.11

	180							240						
Added P (mg kg^{-1})	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P
HFO-P_i	2.58	5.08	5.57	8.42	9.58	14.00	7.54	2.79	4.63	5.79	8.39	9.49	12.59	7.28
% P recovered		10.00	5.98	5.84	4.67	5.71	6.44		7.36	6.00	5.60	4.47	4.90	5.67
HCO_3-P_i	3.17	4.67	5.92	9.92	15.58	20.92	10.03	2.90	4.42	5.63	9.71	15.38	19.25	9.55
% P recovered		6.00	5.50	6.75	8.27	8.88	7.08		6.08	5.46	6.81	8.32	8.18	6.97
OH-P_i	44.08	52.17	60.00	78.67	87.17	103.00	70.85	46.70	53.67	63.33	80.00	93.00	104.00	73.45
% P recovered		32.36	31.84	34.59	28.73	29.46	31.40		27.88	33.26	33.30	30.87	28.65	30.79
D/HCl-P_i	8.00	12.33	15.17	18.17	21.83	24.83	16.72	8.85	13.33	16.92	20.33	23.75	27.17	18.39
% P recovered		17.32	14.34	10.17	9.22	8.42	11.89		17.92	16.14	11.48	9.93	9.16	12.93
C/HCl-P_i	59.00	62.33	68.67	78.67	86.00	98.00	75.45	59.60	64.62	70.67	80.10	89.96	100.54	77.58
% P recovered		13.32	19.34	19.67	18.00	19.50	17.97		20.08	22.14	20.50	20.24	20.47	20.69
$H_2SO_4P_i$	60.67	62.00	67.67	73.67	86.67	93.33	74.00	61.83	65.67	70.17	78.58	89.67	99.17	77.52
% P recovered		5.32	14.00	13.00	17.33	16.33	13.20		15.36	16.68	16.75	18.56	18.67	17.20
HCO_3-P_o	5.08	6.92	7.33	8.33	8.67	10.08	7.74	4.86	6.00	6.46	6.88	7.29	9.00	6.75
% P recovered		7.36	4.50	3.25	2.39	2.50	4.00		4.56	3.20	2.02	1.62	2.07	2.69
OH-P_o	13.33	16.67	20.00	22.33	24.50	26.17	20.50	12.42	15.00	17.08	20.33	23.17	24.83	18.81
% P recovered		13.36	13.34	9.00	7.45	6.42	9.91		10.32	9.32	7.91	7.17	6.21	8.18
C/HCl-P_o	13.33	14.60	16.40	18.67	20.00	21.33	17.39	13.52	16.71	19.21	20.52	21.75	23.67	19.23
% P recovered		5.08	6.14	5.34	4.45	4.00	5.00		12.76	11.38	7.00	5.49	5.08	8.34
Total P extracted	209.24	236.77	266.73	316.85	360.00	411.66	300.21	213.47	244.05	275.26	324.84	373.46	420.22	308.55
Total % P recovered		110.12	114.98	107.61	100.51	101.21	106.89		122.32	123.58	111.37	106.66	103.38	113.46

Table 3: The effects of the added P and incubation period on the sequentially extracted inorganic P, organic P, and percent P recovered from Loskop soil.

Incubation period (days)	1							60							120						
Added P (mg kg^{-1})	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P
HFO-P_i	5.40	10.67	18.56	39.33	49.89	64.78	31.44	5.25	7.50	10.71	22.08	28.33	33.58	17.91	5.35	7.09	7.96	15.58	19.00	23.08	13.01
% P recovered		21.08	26.32	33.93	29.66	29.69	28.14		9.00	10.92	16.83	15.39	14.17	13.26		6.96	5.22	10.23	9.10	8.87	8.08
HCO_3-P_i	12.83	17.76	30.08	45.12	59.29	74.95	40.01	8.11	10.92	15.42	28.83	40.28	49.03	25.43	6.89	9.67	13.42	25.21	33.46	41.75	21.73
% P recovered		19.72	34.50	32.29	30.97	31.06	29.71		11.24	14.62	20.72	21.45	20.46	17.70		11.12	13.06	18.32	17.71	17.43	15.53
OH-P_i	21.43	27.10	39.43	45.57	54.80	62.23	41.76	26.42	32.17	46.33	52.83	65.83	73.25	49.47	31.17	37.50	50.33	62.17	73.33	84.67	56.53
% P recovered		22.68	36.00	24.14	22.25	20.40	25.09		23.00	39.82	26.41	26.27	23.42	27.78		25.32	38.32	31.00	28.11	26.75	29.90
D/HCl-P_i	5.97	7.50	8.00	9.28	9.93	10.43	8.52	5.99	8.95	9.13	10.14	10.63	11.96	9.47	6.17	9.43	10.22	11.70	12.13	13.25	10.48
% P recovered		6.12	4.06	3.31	2.64	2.23	3.67		11.64	6.28	4.15	3.09	2.99	5.67		13.04	8.10	5.53	3.97	3.54	6.84
C/HCl-P_i	29.33	32.27	35.30	37.67	38.53	39.87	35.50	31.50	33.00	35.08	41.58	42.17	48.42	38.63	31.92	38.58	40.50	47.75	55.25	60.58	45.76
% P recovered		11.76	11.94	8.34	6.13	5.27	8.69		6.00	7.16	10.08	7.11	8.46	7.76		26.64	17.16	15.83	15.55	14.33	17.90
H_2SO_4-P_i	39.83	40.00	40.50	41.00	42.50	45.67	41.58	40.67	41.76	41.92	52.03	57.35	66.17	49.98	41.38	41.80	45.13	52.25	59.69	70.48	51.79
% P recovered		0.68	1.34	1.17	1.78	2.92	1.58		4.36	2.50	11.36	11.12	12.75	8.42		1.68	7.50	10.87	12.21	14.55	9.36
HCO_3-P_o	9.55	10.28	10.54	11.33	11.35	12.18	10.87	10.00	11.42	12.88	16.08	17.30	20.30	14.66	10.25	12.48	13.55	16.25	17.92	18.84	14.88
% P recovered		2.92	1.98	1.78	1.20	1.32	1.84		5.68	5.76	6.08	4.87	5.15	5.51		8.92	6.60	6.00	5.11	4.30	6.19
OH-P_o	7.38	8.48	8.85	10.12	10.30	10.35	9.25	9.81	11.96	13.00	13.71	15.71	16.13	13.39	10.17	13.50	14.71	16.42	18.33	19.83	15.49
% P recovered		4.40	2.94	2.74	1.95	1.49	2.70		8.60	6.38	3.90	3.93	3.16	5.19		13.32	9.08	6.25	5.44	4.83	7.78
C/HCl-P_o	9.20	9.96	10.00	10.18	10.71	11.78	10.31	8.78	10.11	10.78	11.61	14.50	15.05	11.81	9.94	11.25	11.78	13.72	14.06	15.89	12.77
% P recovered		3.04	1.60	0.98	1.01	1.29	1.58		5.32	4.00	2.83	3.81	3.14	3.82		5.24	3.68	3.78	2.75	2.98	3.68
Total P extracted	140.92	164.02	201.26	249.60	287.30	332.24	229.22	146.53	167.79	195.25	248.89	292.10	333.89	230.74	153.24	181.30	207.60	261.05	303.17	348.37	242.46
Total % P recovered		92.40	120.68	108.68	97.59	95.66	103.00		85.04	97.44	102.36	97.05	93.68	95.11		112.24	108.72	107.81	99.95	97.57	105.26

Incubation period (days)	180							240						
Added P (mg kg^{-1})	0	25	50	100	150	200	Average-P	0	25	50	100	150	200	Average-P
HFO-P_i	4.92	6.84	8.92	14.33	17.75	19.58	12.06	4.54	6.46	7.21	11.50	15.57	16.75	10.34
% P recovered		7.68	8.00	9.41	8.55	7.33	8.19		7.68	5.34	6.96	7.35	6.11	6.69
HCO_3-P_i	6.00	7.62	8.13	16.00	22.00	28.92	14.78	5.56	6.89	7.67	13.17	18.83	23.17	12.55
% P recovered		6.48	4.26	10.00	10.67	11.46	8.57		5.32	4.22	7.61	8.85	8.81	6.96
OH-P_i	34.92	40.17	53.50	72.58	83.17	89.50	62.31	37.83	45.33	59.50	78.58	87.83	96.07	67.52
% P recovered		21.00	37.16	37.66	32.17	27.29	31.06		30.00	43.34	40.75	33.33	29.12	35.31
D/HCl-P_i	6.25	10.15	11.18	12.06	14.58	14.67	11.48	6.08	11.33	11.67	12.92	16.07	16.42	12.42
% P recovered		15.60	9.86	5.81	5.55	4.21	8.21		21.00	11.18	6.84	6.66	5.17	10.17
C/HCl-P_i	32.33	40.42	42.17	53.67	60.25	65.63	49.08	34.83	39.42	44.67	55.08	64.33	71.08	51.57
% P recovered		32.36	19.68	21.34	18.61	16.65	21.73		18.36	19.68	20.25	19.67	18.13	19.22
H_2SO_4-P_i	41.97	42.36	46.13	57.59	61.15	71.45	53.44	42.59	44.27	50.78	60.16	71.40	79.82	58.17
% P recovered		1.56	8.32	15.62	12.79	14.74	10.61		6.72	16.38	17.57	19.21	18.62	15.70
HCO_3-P_o	8.50	10.21	11.75	13.79	15.09	15.88	12.54	7.83	8.83	10.92	12.25	14.00	15.67	11.58
% P recovered		6.84	6.50	5.29	4.39	3.69	5.34		4.00	6.18	4.42	4.11	3.92	4.53
OH-P_o	11.38	13.57	14.86	17.40	18.92	20.67	16.13	11.58	13.18	14.50	16.13	17.13	19.09	15.27
% P recovered		8.76	6.96	6.02	5.03	4.65	6.28		6.40	5.84	4.55	3.70	3.76	4.85
C/HCl-P_o	9.28	11.89	13.11	14.22	15.38	16.89	13.46	9.39	13.39	15.94	20.05	21.22	22.28	17.05
% P recovered		10.44	7.66	4.94	4.07	3.81	6.18		16.00	13.10	10.66	7.89	6.45	10.82
Total P extracted	155.55	183.23	209.75	271.64	308.29	343.19	245.28	160.23	189.10	222.86	279.84	326.38	360.35	256.46
Total % P recovered		110.72	108.40	116.09	101.83	93.82	106.17		115.48	125.26	119.61	110.77	100.06	114.24

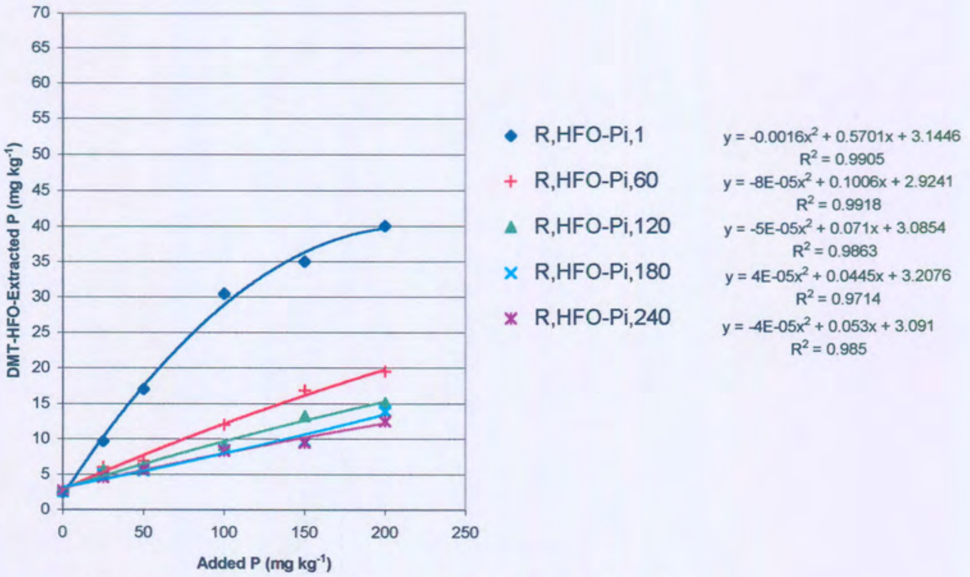

Fig. 2a. The effects of the added P and incubation time on the DMT-HFO extracted inorganic P (P_i) from the Rustenburg soil.

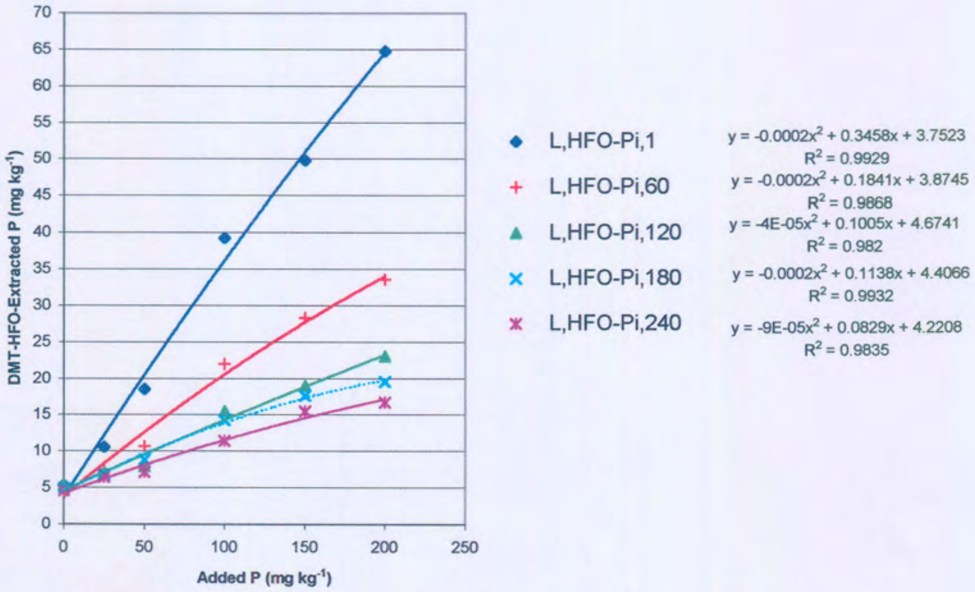

Fig. 2b. The effects of the added P and incubation time on the DMT-HFO extracted inorganic P (P_i) from the Loskop soil.

The proportion of DMT-HFO-P_i as a fraction of the extracted total soil P pool was generally low for Rustenburg but relatively higher for Loskop soil. The proportions increased with the added P levels but were markedly reduced during the incubation period (Tables 4-8). For example, the Rustenburg soil had 1.35-10.75 % after 1 day (Table 4a) but only 1.31-3.00 % after 240 days (Table 8a) of incubation from 0-200 mg kg^{-1} of added P. Meanwhile the Loskop soil had 3.83-19.50 % after 1 day (Table 4b) but only 2.83-4.65 % after 240 days (Table 8b) of incubation. The changes in the distribution of soil P could have resulted from the chemical changes brought about during the moist incubation period, which could have altered the extractability of soil P pools. The changes could also have resulted from the conversion of P through microbial activities even in the control sample, which was subsequently released to the soil on deaths of the cells (Chauhan et al., 1981).

The differences in the DMT-HFO extractable P_i, percent recoveries of the applied P, and the distribution as fractions of the extracted total soil P pools in the two soils could be due to the differences in the clay contents and types, and organic matter contents. Rustenburg soil had more clay and organic matter than the Loskop soil (Table 1). The clay contents (Rustenburg, 51%; Loskop, 19%), coupled with the higher amounts of the kaolinites (Rustenburg, 52 %; Loskop, 37%) could have been the major reasons for the lower percent recovery of the added P from the Rustenburg soil with the prolonged incubation periods (Dalal 1973; Loganathan et al., 1987; Sanchez et al., 1991).

The solution P recoveries of a soil have also been reported to be 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 to 85 %) was desorbed by anion-exchange resin (equivalent to DMT-HFO) after 31 days of incubation. Sharpley, et al. (1984) on the other hand, reported that in 78 soils of the US treated to 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 anion-exchange resin. The high recoveries in the Raven and Hossner

(1994) study were probably due to the relatively short incubation time (31 days) and the absence of wetting and drying cycles.

Both soils showed that as more P was added, the percent recoveries stayed more or less the same within each incubation period, and thus not correspondingly more solution-P_i was made available (Tables 2 and 3). Earlier, Kafkafi et al. (1967) had reported that when P is added to a soil, some of it is converted directly into the fixed form (insoluble and residual P). This could have affected the percent P recovered as noted in this experiment.

3a: (ii). The effects of the added P and incubation period on the 0.5M $NaHCO_3$-extracted P (P_i and P_o)

0.5M $NaHCO_3$-extracted P_i:

The results of the different P and incubation treatments are presented in Tables 2 and 3, 4-8, Figures 3a and b, and Appendices I Nos. 2, and 14 respectively for Rustenburg and Loskop soils. The extracted $-HCO_3$-P_i fraction significantly increased ($P = 0.01$) with increasing levels of added P for both the Rustenburg and Loskop soils (Appendices I Nos. 2, and 14). However, the amounts extracted for each level of added P decreased significantly with the increasing days of incubation as can be seen by the reduction in the percent P recovered (Tables 2 and 3). The trend however, was similar to the HFO-P_i extracts for both soils.

For the Rustenburg soil the amounts of $-HCO_3$-P_i extracted varied between 6.30 and 67.13 (1 day) and 2.90-19.25 mg kg^{-1} (240 days) from the lowest to the highest P applications (Table 2). This represented a percent P recovery of approximately 30 % after one day, but the P recovered reduced to approximately 10 % after 60 days of incubation. For the longer incubation periods the percent P recovered tended to increase with higher P applications but the amount of P extracted were lower. This tendency indicates that whereas for the DMT-HFO extracts the percent P recoveries decreased there were corresponding increases with the $-HCO_3$-extract, showing that some soluble P was transferred to the $-HCO_3$-extractable P pool.

For the Loskop soil however, the changes in the percent P recoveries were more gradual up to 180 days of incubation. This again clearly shows the differences between the two soils. For the Rustenburg soil, most of the added P was transformed between the first and 60 days of incubation, after which only small amounts of $-HCO_3$-P_i could be extracted. However, for the Loskop soil, the transformation was slower, and fairly large percentage of the applied P was bicarbonate extractable up to 180 days of incubation (Table 3 and Fig. 3b). Here again it was evident that some of the DMT-HFO-P_i was transferred to the $-HCO_3$-extractable P pool.

Here again the differences in the $-HCO_3$ extractable P_i and the percent P recoveries of the two soils could be due to the differences in the clay and organic matter contents and types. As it was stated earlier in relation to the DMT-HFO-P_i extracts, the clay content coupled with the high amounts of the kaolinites and possibly Fe and Al oxihydroxides could have contributed to the lower percent P recoveries from the Rustenburg soil because more P was transformed to less bicarbonate extractable P (Dalal 1973; Loganathan et al., 1987; Sanchez et al., 1991).

Furthermore, the noted differences in the amounts extracted and the percent P recovered could also have been influenced by the mineralization of P from the readily decomposable soil organic matter and the deaths of microbial cells during the incubation period. According to Tables 2 and 3 the percent P recoveries were higher at the lower P than the higher P application rates and more from the Rustenburg soil that had relatively higher organic matter content. Tiessen et al. (1984) had shown that the available (labile) P was largely contributed to by the mineralization of the bicarbonate $P_{o.}$

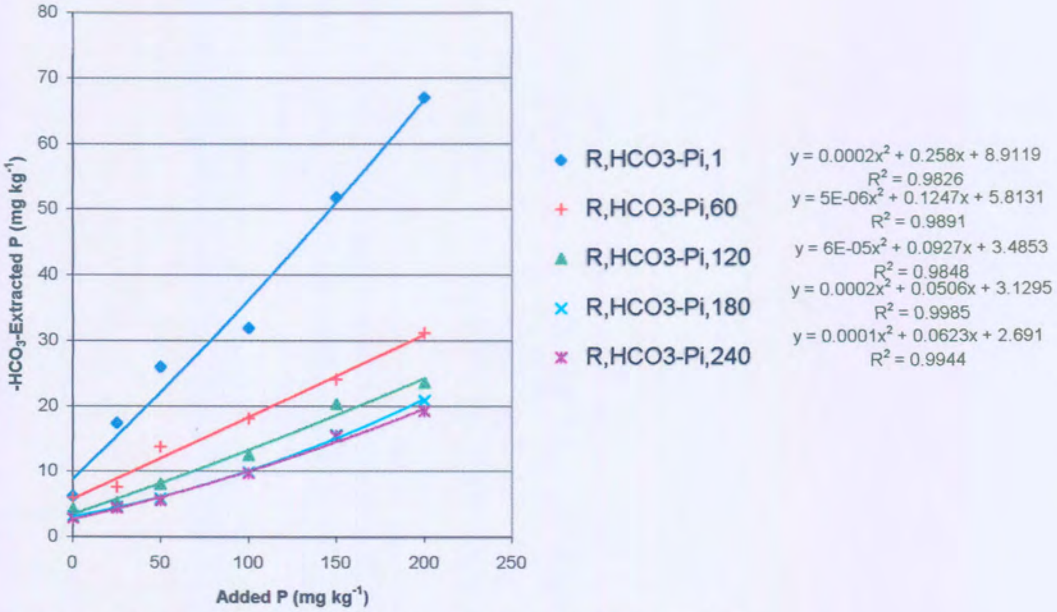

Fig. 3a. The effects of the added P and incubation time on the bicarbonate (-HCO$_3$) extracted inorganic P (P$_i$) from the Rustenburg soil.

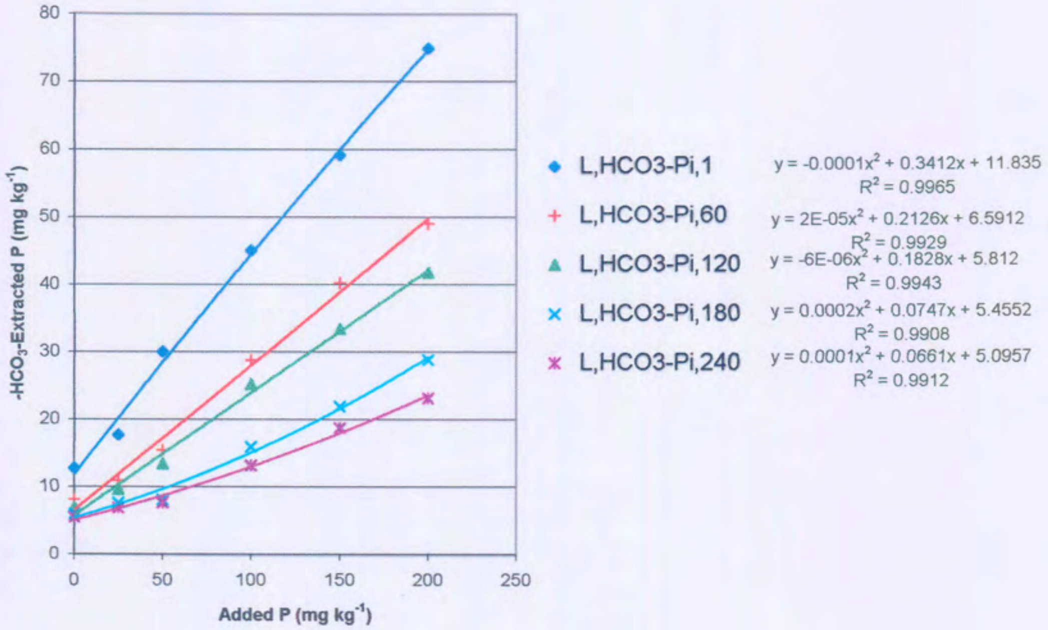

Fig. 3b. The effects of the added P and incubation time on the bicarbonate (-HCO$_3$) extracted inorganic P (P$_i$) from the Loskop soil.

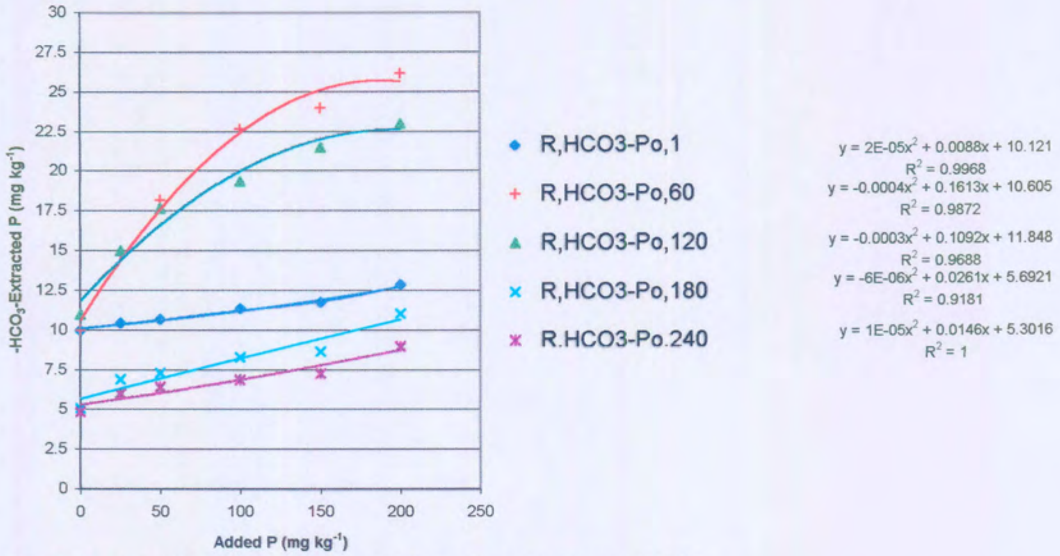

Fig. 4a. The effects of the added P and incubation time on the bicarbonate (-HCO$_3$) extracted organic P (P$_o$) from the Rustenburg soil.

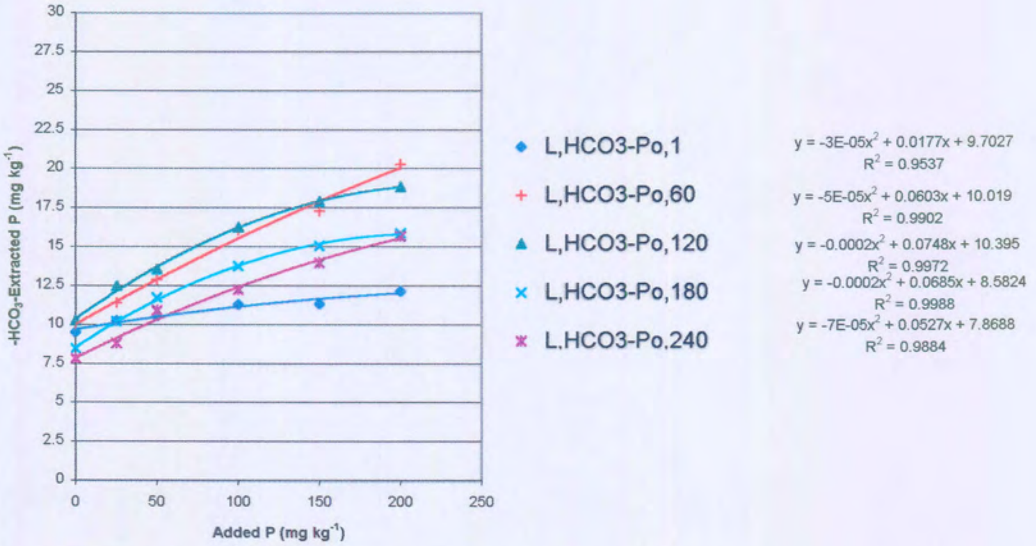

Fig. 4b. The effects of the added P and incubation time on the bicarbonate (-HCO$_3$) extracted organic P (P$_o$) from the Loskop soil.

The contributions of $–HCO_3$-P_i extracts to the extracted total soil P pool were initially relatively lower for the Rustenburg compared to the Loskop soil. The contributions increased with the increasing levels of the added P but were markedly reduced by increasing incubation periods. Thus, for Rustenburg soil the contributions ranged from 3.40-18.00 % (1 day, Table 4a) to 1.36-4.58 % (240 days, Table 8a). While for Loskop soil the contributions varied from 9.10-22.56 % (1 day, Table 4b) to 3.47-6.43 % (240 days, Table 8b) between the lowest and the highest applied P respectively. This also indicated that both soils lost large proportions of $–HCO_3$-P_i to stable P pools during the incubation period.

As the $NaHCO_3$-P_i is classified as labile P fraction, it is recognized along with DMT-HFO-P_i (solution P_i) as the most readily available for plant uptake and growth. It is therefore expected that they would reflect seasonal short-term changes in plant available P, and consistent with this, the largest proportion of P lost from the individual P pools would occur from these two pools (Hedley et al., 1982; Bowman et al., 1998). Thus, prolonging incubation periods from 1-240 days generally reduced the availability of labile P, due to different adsorption and fixation reactions similar to the solution DMT-HFO-P_i shown earlier. The reductions were however, noticeably more gradual for Loskop soil that is a relatively light soil with less clay and soil organic matter (Oades and Ladd, 1977; Dalal, 1977).

0.5M $NaHCO_3$-extracted P_0:

The amounts of the bicarbonate organic P ($–HCO_3$-P_0) extracted from all the added P levels were slightly higher for Rustenburg than for Loskop soil between 1 and 120 days of incubation (Tables 2 and 3; Figs. 4a and b). For longer incubation periods the extractable P_0 became very low indicating that the organic P was mineralised within 120 days where after it became depleted especially in the Rustenburg soil. In the Loskop soil this fraction did not become as depleted as in the Rustenburg soil. The noted differences in the amounts extracted and the percent P recovered could have been due to the increased microbial populations and activities during the incubation period.

The contributions of –HCO_3-P_o to the total soil P pool were also low for both soils. The fractions remained stable although slight decreases were noticeable with increased P levels and the incubation periods, indicating possible enhancement of P_o mineralization in both cases (Tables 4a,b-8a and b; Figs. 4a and b). Thus the extracted -HCO_3-P_o (highest and lowest values) varied from 6.66 % (60 days) to 2.19 % (240 days), as fraction of the total soil P pool in the Rustenburg soil, while in the Loskop soil, -HCO_3-P_o accounted for 6.35 % (60 days) to 4.48 % (240 days) highest and lowest values respectively. In related long-term field trials in Mpumalanga, du Preez and Claassens (1999) working with Avalon and Clovelly soils found the values ranged from 5.20-8.75 %, and 1.70-3.40 % respectively. Although Tiessen, et al. (1984) had shown that 80 % of the availability in resin P (equivalent to DMT-HFO-P_i) was accounted for by variations in the bicarbonate P_o, but our results show that the contribution of the bicarbonate P_o is marginal in both soils.

Total plant-available P (DMT–HFO-P and $NaHCO_3$-P extracts)

According to the data in Tables 4a, b - 8a, b the immediately plant-available P_i (HFO-P_i + -HCO_3-P_i) of Rustenburg soil accounted for 4.75 % of the total soil P pool where no P was added and 28.75 % where 200 mg P kg^{-1} was added after 1 day of incubation. These values decreased to 2.67 % and 7.58 % after 240 days of incubation respectively.

While for the Loskop soil the values were 12.93 % of the total soil P pool where no P was applied and increased to 42.06 % where 200 mg kg^{-1} was added after 1 day of incubation, but decreased to 6.30 % and 11.08 % after 240 days of incubation respectively. The plant-available P_i thus accounted for progressively smaller fractions of the extracted total soil P pools as incubation progressed from 1 to 240 days.

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

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	2.50	6.30	30.00	6.73	50.93	55.27	10.00	13.80	9.67	33.47	151.73	185.20	185.20
	% of Total P	1.35	3.40	16.20	3.63	27.50	29.84	5.40	7.45	5.22	18.07	81.93	100.00	
25	Extracted P	9.73	17.42	35.80	7.14	51.60	56.17	10.47	14.47	9.73	34.67	177.86	212.53	210.20
	% of Total P	4.58	8.20	16.84	3.36	24.28	26.43	4.93	6.81	4.58	16.31	83.69	101.11	
50	Extracted P	17.10	25.99	39.37	9.76	53.83	56.83	10.72	14.97	10.10	35.79	202.88	238.67	235.20
	% of Total P	7.16	10.89	16.50	4.09	22.55	23.81	4.49	6.27	4.23	15.00	85.00	101.48	
100	Extracted P	30.59	32.00	61.03	13.40	56.93	57.33	11.37	15.10	10.50	36.97	251.28	288.25	285.20
	% of Total P	10.61	11.10	21.17	4.65	19.75	19.89	3.94	5.24	3.64	12.83	87.17	101.07	
150	Extracted P	33.12	41.89	68.20	14.05	60.97	59.50	11.77	15.90	13.65	41.32	277.73	319.05	335.20
	% of Total P	10.38	13.13	21.38	4.40	19.11	18.65	3.69	4.98	4.28	12.95	87.05	95.18	
200	Extracted P	40.09	67.13	82.53	15.07	63.73	61.67	12.90	15.97	13.80	42.67	330.22	372.89	385.20
	% of Total P	10.75	18.00	22.13	4.04	17.09	16.54	3.46	4.28	3.70	11.44	88.56	96.80	
Average	Extracted P	22.19	31.79	52.82	11.03	56.33	57.80	11.21	15.04	11.24	37.48	231.95	269.43	272.70
Average	% of Total P	7.47	10.79	19.04	4.03	21.71	22.53	4.32	5.84	4.28	14.43	85.57	99.27	

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

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	5.40	12.83	21.43	5.97	29.33	39.83	9.55	7.38	9.20	26.13	114.79	140.92	140.92
	% of Total P	3.83	9.10	15.21	4.24	20.81	28.26	6.78	5.24	6.53	18.54	81.46	100.00	
25	Extracted P	10.67	17.76	27.10	7.50	32.27	40.00	10.28	8.48	9.96	28.72	135.30	164.02	165.92
	% of Total P	6.51	10.83	16.52	4.57	19.67	24.39	6.27	5.17	6.07	17.51	82.49	98.85	
50	Extracted P	18.56	30.08	39.43	8.00	35.30	40.50	10.54	8.85	10.00	29.39	171.87	201.26	190.92
	% of Total P	9.22	14.95	19.59	3.97	17.54	20.12	5.24	4.40	4.97	14.60	85.40	105.42	
100	Extracted P	39.33	45.12	45.57	9.28	37.67	41.00	11.33	10.12	10.18	31.63	217.97	249.60	240.92
	% of Total P	15.76	18.08	18.26	3.72	15.09	16.43	4.54	4.05	4.08	12.67	87.33	103.60	
150	Extracted P	49.89	59.29	54.80	9.93	38.53	42.50	11.35	10.30	10.71	32.36	254.94	287.30	290.92
	% of Total P	17.37	20.64	19.07	3.46	13.41	14.79	3.95	3.59	3.73	11.26	88.74	98.76	
200	Extracted P	64.78	74.95	62.23	10.43	39.87	45.67	12.18	10.35	11.78	34.31	297.93	332.24	340.92
	% of Total P	19.50	22.56	18.73	3.14	12.00	13.75	3.67	3.12	3.55	10.33	89.67	97.45	
Average	Extracted P	31.44	40.01	41.76	8.52	35.50	41.58	10.87	9.25	10.31	30.42	198.80	229.22	228.42
Average	% of Total P	12.03	16.03	17.90	3.85	16.42	19.62	5.07	4.26	4.82	14.15	85.85	100.68	

Table 5a. The effects of the added P on the changes and distribution of P into different P pools after 60 days of incubation of Rustenburg soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	2.87	6.00	34.33	6.92	58.00	55.73	10.00	14.17	11.75	35.92	163.85	199.77	199.77
	% of Total P	1.44	3.00	17.18	3.46	29.03	27.90	5.01	7.09	5.88	17.98	82.02	100.00	
25	Extracted P	6.08	7.58	42.00	9.42	60.00	56.67	14.75	16.34	12.17	43.26	181.75	225.01	224.77
	% of Total P	2.70	3.37	18.67	4.19	26.67	25.19	6.56	7.26	5.41	19.23	80.77	100.11	
50	Extracted P	6.92	13.75	52.08	12.33	62.33	59.00	18.17	20.63	13.50	52.30	206.41	258.71	249.77
	% of Total P	2.67	5.31	20.13	4.77	24.09	22.81	7.02	7.97	5.22	20.22	79.78	103.58	
100	Extracted P	12.00	18.08	68.33	15.08	65.67	65.22	22.67	24.25	16.25	63.17	244.38	307.55	299.77
	% of Total P	3.90	5.88	22.22	4.90	21.35	21.21	7.37	7.88	5.28	20.54	79.46	102.60	
150	Extracted P	16.92	24.08	83.67	17.58	70.33	72.38	24.00	25.92	17.93	67.85	284.96	352.81	349.77
	% of Total P	4.80	6.83	23.72	4.98	19.93	20.52	6.80	7.35	5.08	19.23	80.77	100.87	
200	Extracted P	19.58	31.25	94.42	19.92	75.33	80.47	26.17	26.79	19.25	72.21	320.97	393.18	399.77
	% of Total P	4.98	7.95	24.01	5.07	19.16	20.47	6.66	6.81	4.90	18.37	81.63	98.35	
Average	Extracted P	10.73	16.79	62.47	13.54	65.28	64.91	19.29	21.35	15.14	55.79	233.72	289.51	287.27
Average	% of Total P	3.42	5.39	20.99	4.56	23.37	23.01	6.57	7.40	5.30	19.26	80.74	100.92	

Table 5b. The effects of the added P on the changes and distribution of P into different P pools after 60 days of incubation of Loskop soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	5.25	8.11	26.42	5.99	31.50	40.67	10.00	9.81	8.78	28.59	117.94	146.53	146.53
	% of Total P	3.58	5.53	18.03	4.09	21.50	27.76	6.82	6.69	5.99	19.51	80.49	100.00	
25	Extracted P	7.50	10.92	32.17	8.95	33.00	41.76	11.42	11.96	10.11	33.49	134.30	167.79	171.53
	% of Total P	4.47	6.51	19.17	5.33	19.67	24.89	6.81	7.13	6.03	19.96	80.04	97.82	
50	Extracted P	10.71	15.42	46.33	9.13	35.08	41.92	12.88	13.00	10.78	36.66	158.59	195.25	196.53
	% of Total P	5.49	7.90	23.73	4.68	17.97	21.47	6.60	6.66	5.52	18.78	81.22	99.35	
100	Extracted P	22.08	28.83	52.83	10.14	41.58	52.03	16.08	13.71	11.61	41.40	207.49	248.89	246.53
	% of Total P	8.87	11.58	21.23	4.07	16.71	20.90	6.46	5.51	4.66	16.63	83.37	100.96	
150	Extracted P	28.33	40.28	65.83	10.63	42.17	57.35	17.30	15.71	14.50	47.51	244.59	292.10	296.53
	% of Total P	9.70	13.79	22.54	3.64	14.44	19.63	5.92	5.38	4.96	16.26	83.74	98.51	
200	Extracted P	33.58	49.03	73.25	11.96	48.42	66.17	20.30	16.13	15.05	51.48	282.41	333.89	346.53
	% of Total P	10.06	14.68	21.94	3.58	14.50	19.82	6.08	4.83	4.51	15.42	84.58	96.35	
Average	Extracted P	17.91	25.43	49.47	9.47	38.63	49.98	14.66	13.39	11.81	39.86	190.89	230.74	234.03
Average	% of Total P	7.03	10.00	21.11	4.23	17.46	22.41	6.45	6.03	5.28	17.76	82.24	98.83	

Table 6a. The effects of the added P on the changes and distribution of P into different P pools after 120 days of incubation of Rustenburg soil.

Added P (mg kg^{-1})	P Recovered	HFO-P$_i$	HCO$_3$-P$_i$	OH-P$_i$	D/HCl-P$_i$	C/HCl-P$_i$	H$_2$SO$_4$-P$_i$	HCO$_3$-P$_o$	OH-P$_o$	C/HCl-P$_o$	TOT-P$_o$	TOT-P$_i$	Extracted TOT-P	Expected TOT-P
0	Extracted P	2.75	4.20	43.42	7.25	58.33	56.50	11.00	15.21	12.83	39.04	172.45	211.49	211.49
	% of Total P	1.30	1.99	20.53	3.43	27.58	26.72	5.20	7.19	6.07	18.46	81.54	100.00	
25	Extracted P	5.65	5.17	48.25	10.17	61.33	58.83	15.00	17.25	13.17	45.42	189.40	234.82	236.49
	% of Total P	2.41	2.20	20.55	4.33	26.12	25.05	6.39	7.35	5.61	19.34	80.66	99.29	
50	Extracted P	6.17	8.08	54.17	13.21	65.00	65.67	17.67	22.33	15.00	55.00	212.30	267.30	261.49
	% of Total P	2.31	3.02	20.27	4.94	24.32	24.57	6.61	8.35	5.61	20.58	79.42	102.22	
100	Extracted P	9.17	12.50	72.00	16.08	76.00	74.17	19.33	25.58	18.50	63.41	259.92	323.33	311.49
	% of Total P	2.84	3.87	22.27	4.97	23.51	22.94	5.98	7.91	5.72	19.61	80.39	103.80	
150	Extracted P	13.23	20.33	85.25	18.92	80.67	80.17	21.50	26.88	19.00	67.38	298.57	365.95	361.49
	% of Total P	3.62	5.56	23.30	5.17	22.04	21.91	5.88	7.35	5.19	18.41	81.59	101.23	
200	Extracted P	15.17	23.58	98.00	22.04	93.00	89.50	23.00	28.08	20.67	71.75	341.29	413.04	411.49
	% of Total P	3.67	5.71	23.73	5.34	22.52	21.67	5.57	6.80	5.00	17.37	82.63	100.38	
Average	Extracted P	8.69	12.31	66.85	14.61	72.39	70.81	17.92	22.56	16.53	57.00	245.66	302.66	298.99
Average	% of Total P	2.69	3.72	21.77	4.70	24.35	23.81	5.94	7.49	5.53	18.96	81.04	101.15	

Table 6b. The effects of the added P on the changes and distribution of P into different P pools after 120 days of incubation of Loskop soil.

Added P (mg kg^{-1})	P Recovered	HFO-P$_i$	HCO$_3$-P$_i$	OH-P$_i$	D/HCl-P$_i$	C/HCl-P$_i$	H$_2$SO$_4$-P$_i$	HCO$_3$-P$_o$	OH-P$_o$	C/HCl-P$_o$	TOT-P$_o$	TOT-P$_i$	Extracted TOT-P	Expected TOT-P
0	Extracted P	5.35	6.89	31.17	6.17	31.92	41.38	10.25	10.17	9.94	30.36	122.88	153.24	153.24
	% of Total P	3.49	4.50	20.34	4.03	20.83	27.00	6.69	6.64	6.49	19.81	80.19	100.00	
25	Extracted P	7.09	9.67	37.50	9.43	38.58	41.35	12.48	13.50	11.25	37.23	143.62	180.85	178.24
	% of Total P	3.92	5.35	20.74	5.21	21.33	22.86	6.90	7.46	6.22	20.59	79.41	101.46	
50	Extracted P	7.96	13.42	50.33	10.22	40.50	45.13	13.55	14.71	11.78	40.04	167.56	207.60	203.24
	% of Total P	3.83	6.46	24.24	4.92	19.51	21.74	6.53	7.09	5.67	19.29	80.71	102.15	
100	Extracted P	15.58	25.21	62.17	11.70	47.75	52.25	16.25	16.42	13.72	46.39	214.66	261.05	253.24
	% of Total P	5.97	9.66	23.82	4.48	18.29	20.02	6.22	6.29	5.26	17.77	82.23	103.08	
150	Extracted P	19.00	33.46	73.33	12.13	55.25	59.69	17.92	18.33	14.06	50.31	252.86	303.17	303.24
	% of Total P	6.27	11.04	24.19	4.00	18.22	19.69	5.91	6.05	4.64	16.59	83.41	99.98	
200	Extracted P	23.08	41.75	84.67	13.25	60.58	70.48	18.84	19.83	15.89	54.56	293.81	348.37	353.24
	% of Total P	6.63	11.98	24.30	3.80	17.39	20.23	5.41	5.69	4.56	15.66	84.34	98.62	
Average	Extracted P	13.01	21.73	56.53	10.48	45.76	51.71	14.88	15.49	12.77	43.15	199.23	242.38	240.74
Average	% of Total P	5.02	8.16	22.94	4.41	19.26	21.92	6.28	6.54	5.47	18.29	81.71	100.88	

Table 7a. The effects of the added P on the changes and distribution of P into different P pools after 180 days of incubation of Rustenburg soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	2.58	3.17	44.08	8.00	59.00	60.67	5.08	13.33	13.33	31.74	177.50	209.24	209.24
	% of Total P	1.23	1.52	21.07	3.82	28.20	29.00	2.43	6.37	6.37	15.17	84.83	100.00	
25	Extracted P	5.08	4.67	52.17	12.33	62.33	62.00	6.92	16.67	14.60	38.19	198.58	236.77	234.24
	% of Total P	2.15	1.97	22.03	5.21	26.33	26.19	2.92	7.04	6.17	16.13	83.87	101.08	
50	Extracted P	5.57	5.92	60.00	15.17	68.67	67.67	7.33	20.00	16.40	43.73	223.00	266.73	259.24
	% of Total P	2.09	2.22	22.49	5.69	25.75	25.37	2.75	7.50	6.15	16.39	83.61	102.89	
100	Extracted P	8.42	9.92	78.67	18.17	78.67	73.67	8.33	22.33	18.67	49.33	267.52	316.85	309.24
	% of Total P	2.66	3.13	24.83	5.73	24.83	23.25	2.63	7.05	5.89	15.57	84.43	102.46	
150	Extracted P	9.58	15.58	87.17	21.83	86.00	86.67	8.67	24.50	20.00	53.17	306.83	360.00	359.24
	% of Total P	2.66	4.33	24.21	6.06	23.89	24.08	2.41	6.81	5.56	14.77	85.23	100.21	
200	Extracted P	14.00	20.92	103.00	24.83	98.00	93.33	13.08	26.17	21.33	60.58	354.08	414.66	409.24
	% of Total P	3.38	5.05	24.84	5.99	23.63	22.51	3.15	6.31	5.14	14.61	85.39	101.32	
Average	Extracted P	7.54	10.03	70.85	16.72	75.45	74.00	8.24	20.50	17.39	46.12	254.59	300.71	296.74
Average	% of Total P	2.36	3.04	23.25	5.42	25.44	25.06	2.72	6.85	5.88	15.44	84.56	101.33	

Table 7b. The effects of the added P on the changes and distribution of P into different P pools after 180 days of incubation of Loskop soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	4.92	6.00	34.92	6.25	32.33	41.97	8.50	11.38	9.28	29.16	126.39	155.55	155.55
	% of Total P	3.16	3.86	22.45	4.02	20.78	26.98	5.46	7.32	5.97	18.75	81.25	100.00	
25	Extracted P	6.84	7.62	40.17	10.15	40.42	42.36	10.21	13.57	11.89	35.67	147.56	183.23	180.55
	% of Total P	3.73	4.16	21.92	5.54	22.06	23.12	5.57	7.41	6.49	19.47	80.53	101.48	
50	Extracted P	8.92	8.13	53.50	11.18	42.17	46.13	11.75	14.86	13.11	39.72	170.03	209.75	205.55
	% of Total P	4.25	3.88	25.51	5.33	20.10	21.99	5.60	7.08	6.25	18.94	81.06	102.04	
100	Extracted P	14.33	16.00	72.58	12.06	53.67	57.59	13.79	17.40	14.22	45.41	226.23	271.64	255.55
	% of Total P	5.28	5.89	26.72	4.44	19.76	21.20	5.08	6.41	5.23	16.72	83.28	106.30	
150	Extracted P	17.75	22.00	83.17	14.58	60.25	61.15	15.09	18.92	15.38	49.39	258.90	308.29	305.55
	% of Total P	5.76	7.14	26.98	4.73	19.54	19.84	4.89	6.14	4.99	16.02	83.98	100.90	
200	Extracted P	19.58	28.92	89.50	14.67	65.63	71.45	15.88	20.67	16.89	53.44	289.75	343.19	355.55
	% of Total P	5.71	8.43	26.08	4.27	19.12	20.82	4.63	6.02	4.92	15.57	84.43	96.52	
Average	Extracted P	12.06	14.78	62.31	11.48	49.08	53.44	12.54	16.13	13.46	42.13	203.14	245.28	243.05
Average	% of Total P	4.65	5.56	24.94	4.72	20.23	22.32	5.21	6.73	5.64	17.58	82.42	101.21	

Table 8a. The effects of the added P on the changes and distribution of P into different P pools after 240 days of incubation of Rustenburg soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	2.79	2.90	46.70	8.85	59.60	61.83	4.86	12.42	13.52	30.80	182.67	213.47	213.47
	% of Total P	1.31	1.36	21.88	4.15	27.92	28.96	2.28	5.82	6.33	14.43	85.57	100.00	
25	Extracted P	4.63	4.42	53.67	13.33	64.62	65.67	6.00	15.00	16.71	37.71	206.34	244.05	238.47
	% of Total P	1.90	1.81	21.99	5.46	26.48	26.91	2.46	6.15	6.85	15.45	84.55	102.34	
50	Extracted P	5.79	5.63	63.33	16.92	70.67	70.17	6.46	17.08	19.21	42.75	232.51	275.26	263.47
	% of Total P	2.10	2.05	23.01	6.15	25.67	25.49	2.35	6.21	6.98	15.53	84.47	104.47	
100	Extracted P	8.39	9.71	80.00	20.33	80.10	78.58	6.88	20.33	20.52	47.73	277.11	324.84	313.47
	% of Total P	2.58	2.99	24.63	6.26	24.66	24.19	2.12	6.26	6.32	14.69	85.31	103.63	
150	Extracted P	9.49	15.38	93.00	23.75	89.96	89.67	7.29	23.17	21.75	52.21	321.25	373.46	363.47
	% of Total P	2.54	4.12	24.90	6.36	24.09	24.01	1.95	6.20	5.82	13.98	86.02	102.75	
200	Extracted P	12.59	19.25	104.00	27.17	100.54	99.17	9.00	24.83	23.67	57.50	362.72	420.22	413.47
	% of Total P	3.00	4.58	24.75	6.47	23.93	23.60	2.14	5.91	5.63	13.68	86.32	101.63	
Average	Extracted P	7.28	9.55	73.45	18.39	77.58	77.52	6.75	18.81	19.23	44.78	263.77	308.55	300.97
Average	% of Total P	2.24	2.82	23.53	5.81	25.46	25.53	2.22	6.09	6.32	14.63	85.37	102.47	

Table 8b. The effects of the added P on the changes and distribution of P into different P pools after 240 days of incubation of Loskop soil.

Added P (mg kg^{-1})	P Recovered	HFO-P_i	HCO_3-P_i	OH-P_i	D/HCl-P_i	C/HCl-P_i	H_2SO_4-P_i	HCO_3-P_o	OH-P_o	C/HCl-P_o	TOT-P_o	TOT-P_i	Extracted TOT-P	Expected TOT-P
0	Extracted P	4.54	5.56	37.83	6.08	34.83	42.59	7.83	11.58	9.39	28.80	131.43	160.23	160.23
	% of Total P	2.83	3.47	23.61	3.79	21.74	26.58	4.89	7.23	5.86	17.97	82.03	100.00	
25	Extracted P	6.46	6.89	45.33	11.33	39.42	44.27	8.83	13.18	13.39	35.40	153.70	189.10	185.23
	% of Total P	3.42	3.64	23.97	5.99	20.85	23.41	4.67	6.97	7.08	18.72	81.28	102.09	
50	Extracted P	7.21	7.67	59.50	11.67	44.67	50.78	10.92	14.50	15.94	41.36	181.50	222.86	210.23
	% of Total P	3.24	3.44	26.70	5.24	20.04	22.79	4.90	6.51	7.15	18.56	81.44	106.01	
100	Extracted P	11.50	13.17	78.58	12.92	55.08	60.16	12.25	16.13	20.05	48.43	231.41	279.84	260.23
	% of Total P	4.11	4.71	28.08	4.62	19.68	21.50	4.38	5.76	7.16	17.31	82.69	107.54	
150	Extracted P	15.57	18.83	87.83	16.07	64.33	71.40	14.00	17.13	21.22	52.35	274.03	326.38	310.23
	% of Total P	4.77	5.77	26.91	4.92	19.71	21.88	4.29	5.25	6.50	16.04	83.96	105.21	
200	Extracted P	16.75	23.17	96.07	16.42	71.08	79.82	15.67	19.09	22.28	57.04	303.31	360.35	360.23
	% of Total P	4.65	6.43	26.66	4.56	19.73	22.15	4.35	5.30	6.18	15.83	84.17	100.03	
Average	Extracted P	10.34	12.55	67.52	12.42	51.57	58.17	11.58	15.27	17.05	43.90	212.56	256.46	247.73
Average	% of Total P	3.84	4.58	25.99	4.85	20.29	23.05	4.58	6.17	6.66	17.40	82.60	103.48	

3b: The effects of the added P and the incubation periods on the adsorbed P: Al- Fe-oxihydroxide P, and Ca-bound-P (0.1M NaOH- and 1.0M HCl-P)

3b: (i). The effects of the added P and the incubation period on the 0.1M NaOH-extractable P_i and P_o

0.1M NaOH-extracted P_i:

As it has already been indicated, 0.1M NaOH extracts mainly P_i and P_o held more strongly by chemisorption onto the surfaces of iron and aluminium oxihydroxides. According to Tables 2 and 3 the extracted P_i from this fraction increased highly significantly (P = 0.01) (Appendices I Nos. 4 and 5) with the increased P additions and the increasing incubation time.

For the Rustenburg soil increases were from 30.00–82.53 (1 day) to 46.70-104.00 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} added P. This represented an average percent P recovery of 24.94 % after one day. The percent P recovery increased to an average of 32.62 % after 60 days of incubation. However, longer incubation periods did not increase the percent P recovery significantly, they remained relatively stable at around 30 % in average (Table 2; Fig. 5a). According to Figure 5a, -OH- extracted P increased between 1 and 60 days and thereafter there were no more significant increases in the extracted P. This showed that equilibrium was reached after 60 days of incubation with all the levels of applied P. The contributions to the extracted total soil P pool also remained relatively constant after 60 days, with average values of 21.77-23.53 % between 120-240 days of incubation (Tables 4a and 8a).

The OH extractable P values for Loskop soil varied from 21.43–62.23 (1 day) to 37.83-96.07 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} added P. However, for the Loskop soil, again the changes in extractable P were more gradual up to 240 days of incubation (Table 3; Fig. 5b). The fact that the percent P recoveries between the two soils were relatively close indicates that the transformation reactions of the P were similar but only the amounts involved were different.

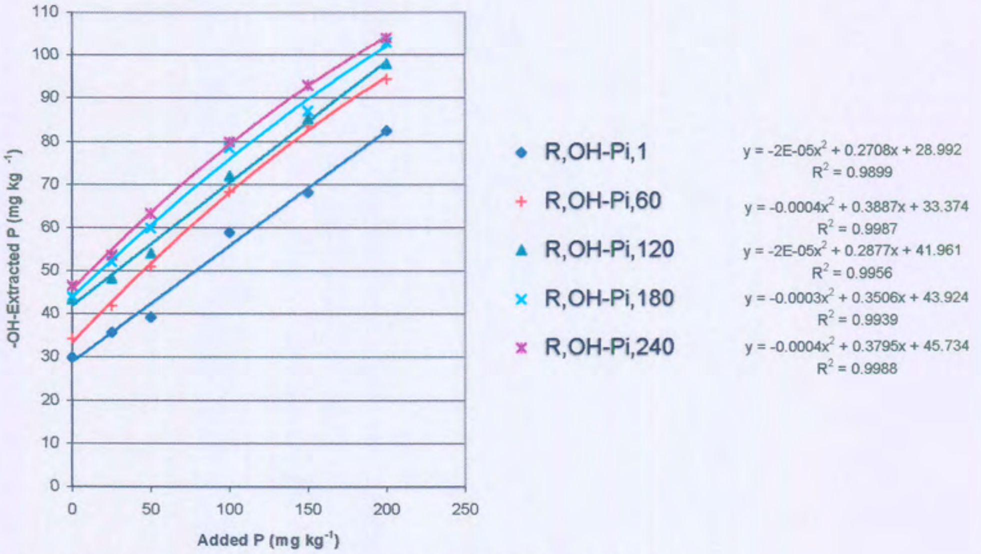

Fig. 5a. The effects of the added P and incubation time on the hydroxide (-OH) extracted inorganic P (P_i) from the Rustenburg soil.

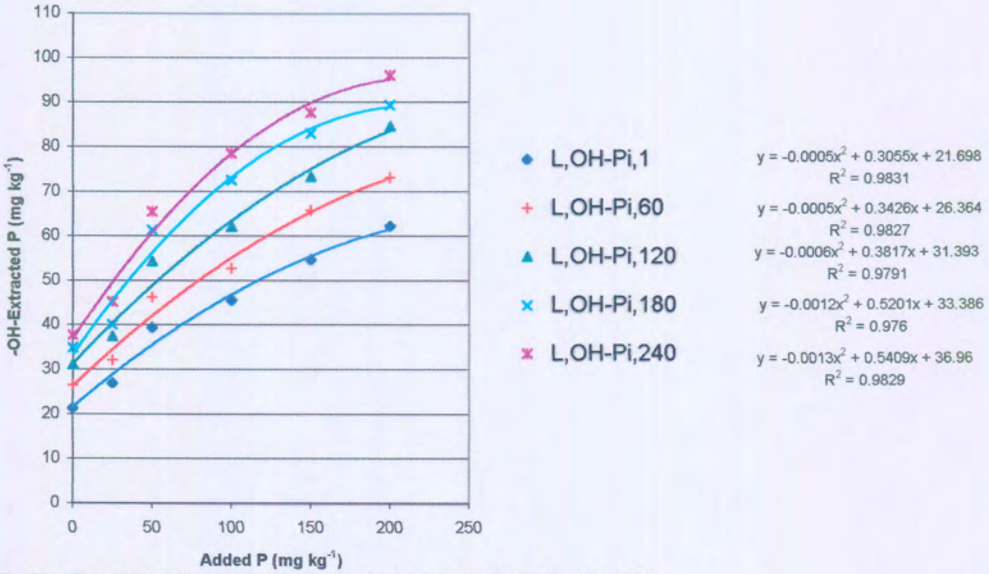

Fig. 5b. The effects of the added P and incubation time on the hydroxide (-OH) extracted inorganic P (P_i) from the Loskop soil.

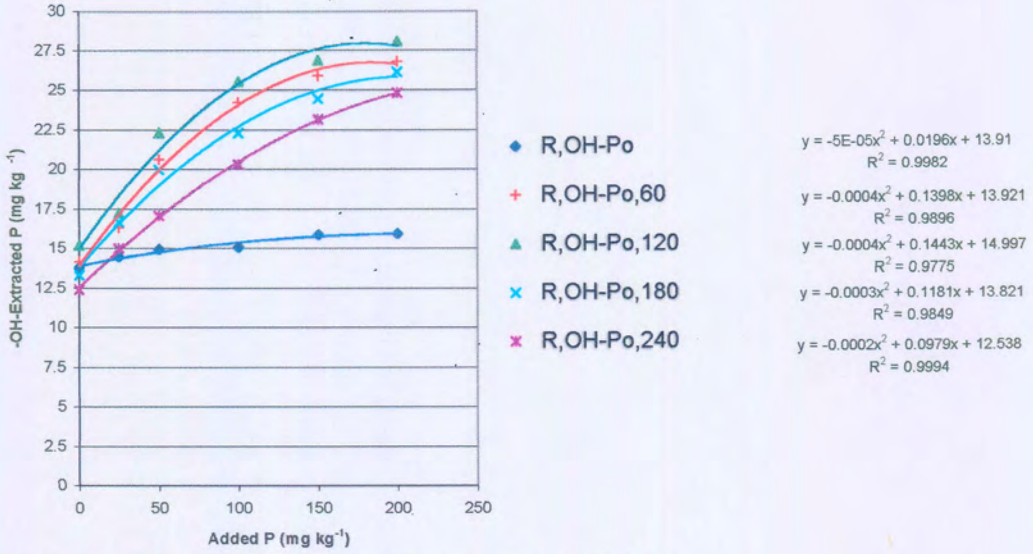

Fig. 6a. The effects of the added P and incubation time on the hydroxide (-OH) extracted organic P (P_o) from the Rustenburg soil.

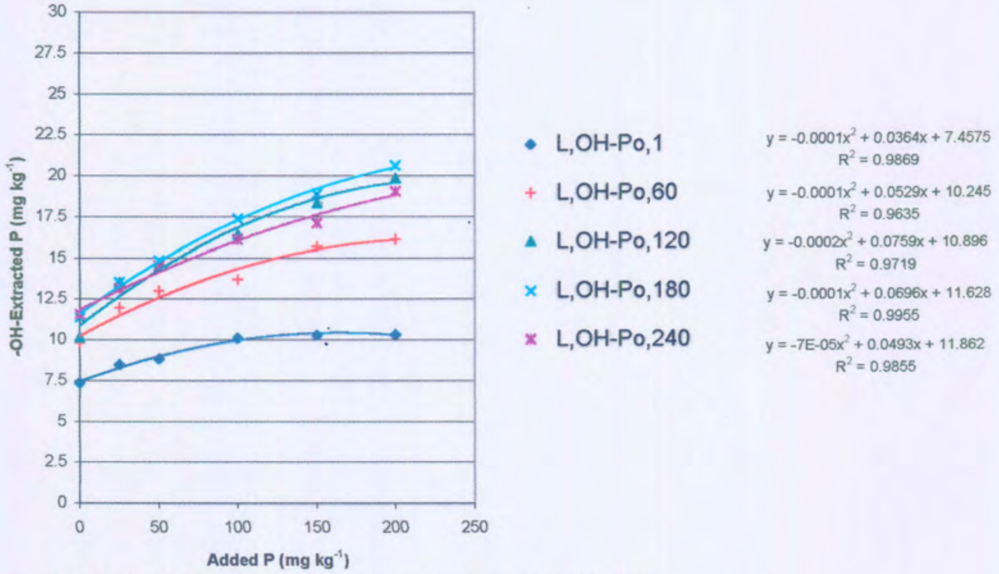

Fig. 6b. The effects of the added P and incubation time on the hydroxide (-OH) extracted organic P (P_o) from the Loskop soil.

The results further showed that both the –OH-P_i extracts and the percent P recoveries each contributed to approximately 25 % of the extracted total soil P pool, and thus the highest contributions to the extracted P_i pools in the two soils (Tables 2-3; 4-8). This would indicate that both soils gained more or less equal amounts of –OH-P_i from the different added P rates during the incubation period. Thus, the contribution of the –OH fraction the total soil P pool was affected in two main ways, by increasing P application rates as well as time of incubation, which increased contributions to the total soil P pool. This may indicate similar abilities of the two soils to transform the applied P to the –OH extractable P pool during the incubation period.

However, the noted differences in the –OH-extractable P_i and the percent P recoveries of the two soils could also be attributed to the differences in the clay contents and the types and to a less extent the organic matter contents. It has already been indicated in earlier discussions that the Rustenburg soil had more clay and organic matter than the Loskop soil (Table 1). The clay content plus the high amount of the kaolinites and to a less extent the mineralization of organic P could have contributed to the higher –OH-extractable P_i, in the Rustenburg soil (Dalal, 1973; Loganathan et al., 1987; Sanchez et al., 1991).

According to Figure 5b it can be concluded that the Loskop soil reached equilibrium with the higher P application rates (> 100 mg kg^{-1}) because of the curve-linear nature of the fitted lines in the graph. It could further show that the soil became saturated with –OH P fraction as more P was applied.

0.1M NaOH-extracted P_o:

According to the values given in the ANOVA (Appendices I Nos. 5 and 17) the –OH-extracted P_o was also significantly influenced by the applied P and incubation periods.

But according to Tables 4-8 the actual contributions of this P fraction to the total P Pool were relatively small (5-7 % for Rustenburg and 4-6 % for Loskop soil). Here again the P_o content increased with increasing incubation time and added P. The incubation time caused increased mineralization of P_o. This became well marked after 120 days when it started to decline in the Rustenburg soil showing that the soil organic matter was becoming depleted. This depletion was not so obvious in the Loskop soil (Tables 2-3; 4-8; Figs. 6a and b). In long-term field trials du Preez and Claassens (1999) found -OH-P_o made up 3.10-9.00% (Avalon) and 4.60-8.60% (Clovelly) of the total soil P pools, while Hedley et al. (1982) found -OH-P_o made up in average 15 % of the total soil P pool (from long-term wheat rotation experiment).

There seemed to have been a stimulation effect of –OH extracted P_o by the mineral P added, which could not be easily explained. The problem could have arisen during the differentiation of the P_i and P_o. There might be some problem in the methodology used, where the P_o may be over estimated at the expense of P_i (Tiessen and Moir, 1993).

3b: (ii). The effects of the added P and incubation periods on the 1.0M HCl-extracted P (P_i)

The variations of the P extracted with 1M HCl were significantly (P = 0. 01) influenced by the P application rate and incubation time (Appendices I Nos. 6 and 18).

The amounts of dilute acid (D/HCl-P_i) extracts for Rustenburg soil ranged from 6.73–15.07 (1 day) to 8.85-27.17 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} of added P (Table 2). Of significance is the fact that at the early stages of incubation the percent recovery was small but after 180 days of incubation there was a significant increase in P extracted and percent recovery. The percent P recovered however decreased with increased applied P rates. This indicates that the transformation of added P into Ca-bound-P_i was relatively low (Table 2; Fig. 7a).

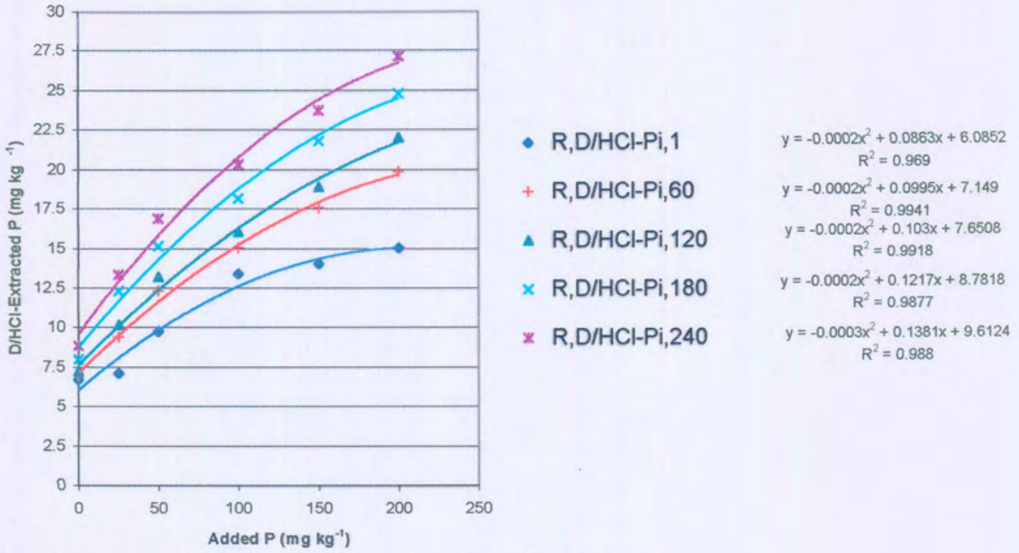

Fig. 7a. The effects of the added P and incubation time on the dilute hydrochloric acid (D/HCl) extracted inorganic P (P_i) from the Rustenburg soil.

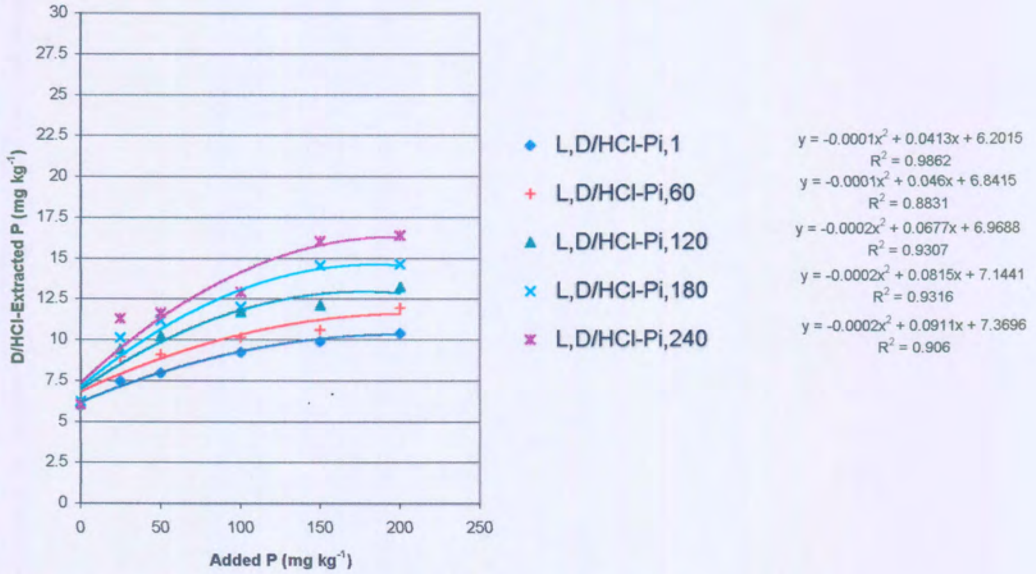

Fig. 7b. The effects of the added P and incubation time on the dilute hydrochloric acid (D/HCl) extracted inorganic P (P_i) from the Loskop soil.

Meanwhile for the Loskop soil, both the amounts of the D/HCl-P_i extracted and the percent P recoveries were lower than for the Rustenburg soil, although there were noted increases in both soils with the increased rates of added P and incubation times (Tables 2 and 3; Figs. 7a and b). Furthermore, the amounts extracted and the percent P recovered followed similar trends as those of the -OH-P_i for both soils. The only differences were in the quantities of the extracts and the tendencies towards equilibria that were more marked for the Loskop soil. The fact that in both soils, but especially the Loskop soil the graphs tended to level off indicates that this fraction becomes easily saturated with higher rates of the applied P (Figs. 7a and b).

The percent recoveries of the added P were also relatively higher for Rustenburg soil, and increased with the days of incubation (Tables 2 and 3). However, in general both the gains (percent P recovered) and the contributions to the total soil P pool were noticeably low for both soils, although were slightly higher for the Rustenburg soil (Tables 2-3; Tables 4-8). Accordingly, Sattell and Morris (1992) found an average of 8 %, and Hedley et al. (1982) found an average of 7 % of the total extracted soil P pool. But, du Preez and Claassens (1999) reported that this fraction contributed less than 1 % of the total soil P pool in the Clovelly soil. The changes in D/HCl-P_i with time and cultivation were small indicating that this fraction was of little importance.

The noted differences in the D/HCl-P_i extracted from Rustenburg and Loskop soils could possibly be attributed to the differences in the clay content and especially the amounts of Ca and Mg, which were relatively higher for the former than for the latter (Table 1). This high Ca and Mg could have resulted in the higher degree of precipitation of the applied P as Ca-P and possibly also as Mg-P. Both these P forms are relatively less available than Al-P or Fe-P (Chang and Jackson, 1957; Loganathan and Sutton, 1987). This may in part also explain why the P applied in the Rustenburg soil remains relatively more unavailable to crop plants than in the Loskop soils.

It has previously been shown that at neutral to higher pH values both the $H_2PO_4^-$ and HPO_4^{-2} ions are found and the main reaction for P adsorption or precipitation (fixation) would be as calcium phosphate (Brady, 1990; Doula, et al., 1996). The reaction can be presented as: $Ca(H_2PO_4)_2.\ H_2O + 2CaCO_3 ====> Ca_3(PO_4)_2 + 2CO_2 + 2H_20$. Chang and Jackson (1957), Thomas and Peaslee (1973), and Loganathan and Sutton (1987), have all indicated that the degree of availability of the adsorbed P_i decreased in the order of Al-P, >Fe- P, >Ca-P, >Mg-P.

Total adsorbed or slow labile P (0.1M NaOH-P_i; and 1.0M HCl-P_i extracts)

The slow or moderately available P (–OH-P_i and D/HCl-P_i) fraction of the total soil P pool accounted for the second largest proportion of P with the Rustenburg soil averaging 23.07 % (1 day) and 29.34 % after 240 days, and for Loskop soil the average values were from 21.75 % (1 day) and 30.84 % after 240 days of incubation.

Thus, there were roughly equal increases in the moderately plant-available P (-OH-P_i and D/HCl-P_i) in both soils. These increases 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 in both soils (Loganathan et al., 1987). However, according to Hedley et al. (1982), during crop growth, specific root processes, such as the release of H^+ ions could be responsible for solubilizing the relatively insoluble 1M HCl P_i.

3c: The effects of the added P and incubation period on the occluded and residual P (conc. HCl- and $H_2SO_4 + H_2O_2$–extracted P

3c: (i). The effects of the added P and incubation periods on the conc. HCl-extracted P (C/HCl-P_i and P_o)

Concentrated HCl extracted significantly different amounts of P from the different added P rates and the incubation times at P = 0.01 (Appendices I Nos. 7, 8, 19, and 20).

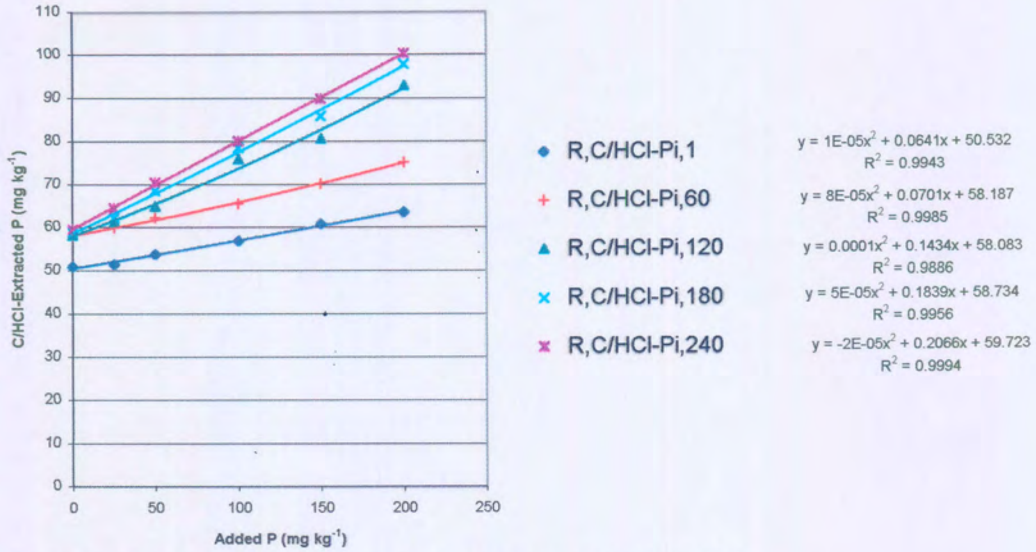

Fig. 8a. The effects of the added P and incubation time on the concentrated hydrochloric acid (C/HCl) extracted inorganic P (P_i) from the Rustenburg soil.

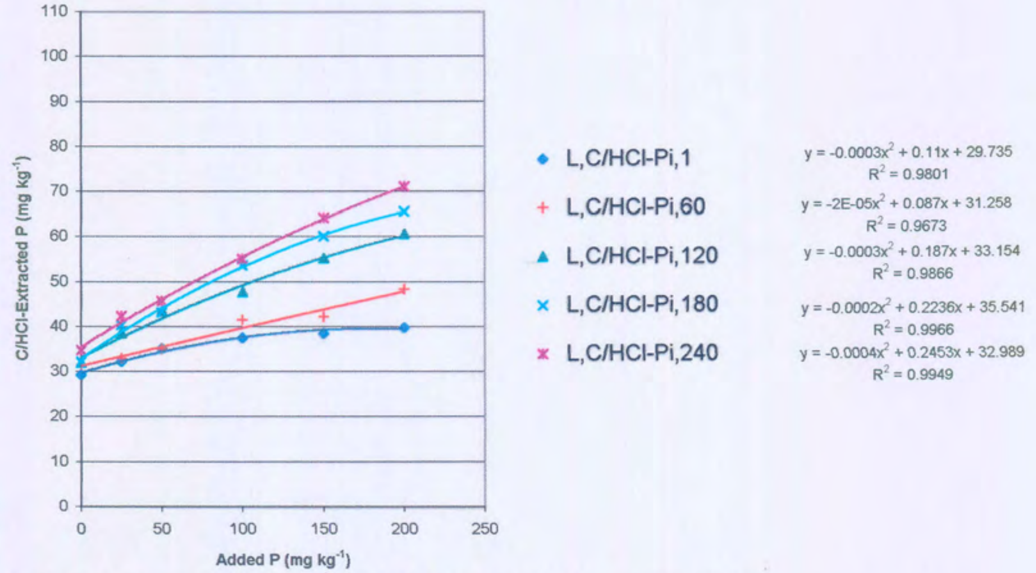

Fig. 8b. The effects of the added P and incubation time on the concentrated hydrochloric acid (C/HCl) extracted inorganic P (P_i) from the Loskop soil.

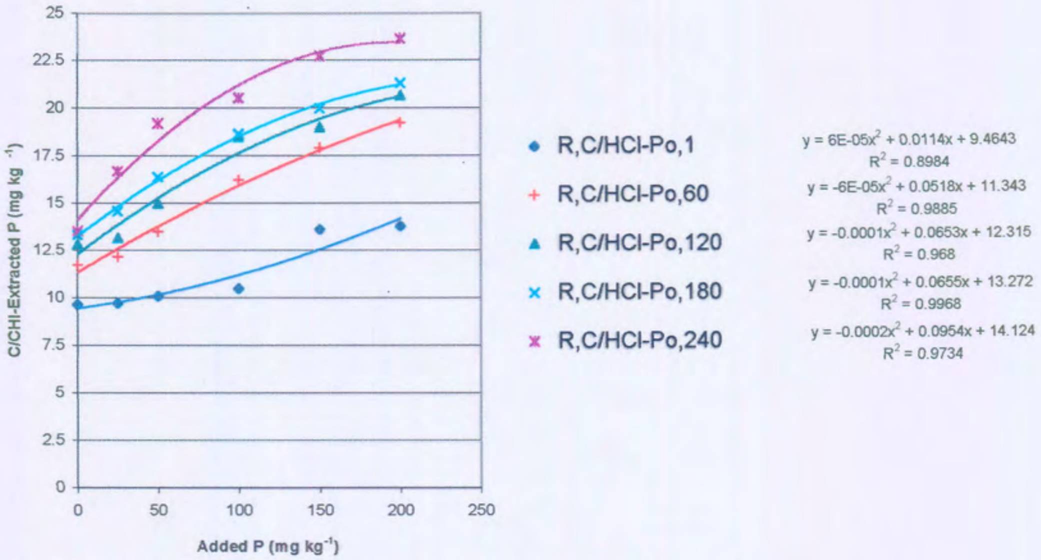

Fig. 9a. The effects of the added P and incubation time on the concentrated hydrochloric acid (C/HCl) extracted organic P (P_o) from the Rustenburg soil.

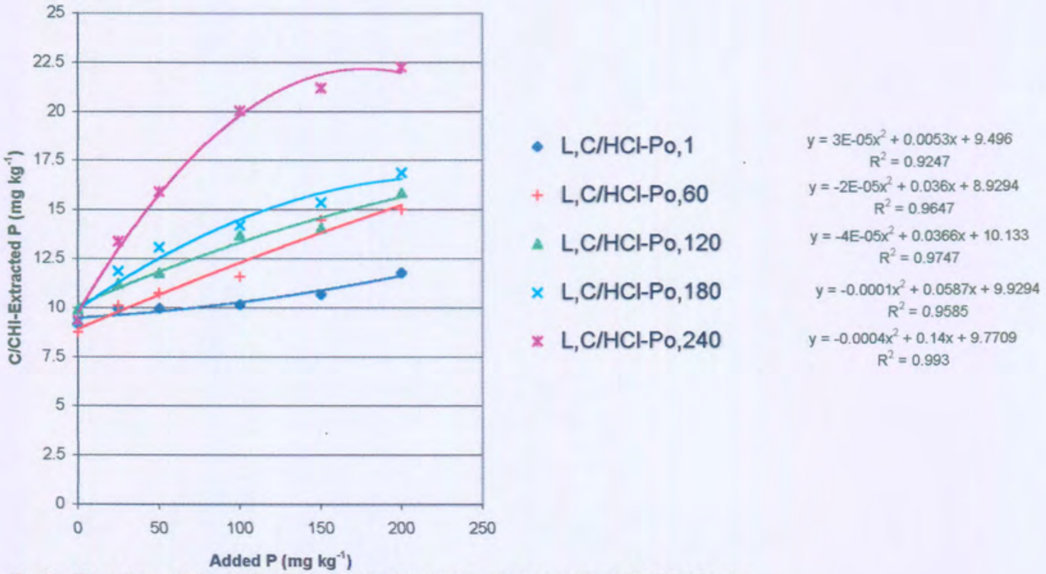

Fig.9b. The effects of the added P and incubation time on the concentrated hydrochloric acid (C/HCl) extracted organic P (P_o) from the Loskop soil.

C/HCl- extracted P_i:

The amounts of the C/HCl-P_i extracts from the Rustenburg soil were high throughout the incubation period and increased with the higher rates of applied P and the incubation period (Table 2; Fig. 8a). The amounts ranged from 50.93–63.73 after 1 day and 59.60-100.54 mg kg^{-1} after 240 days from the lowest and highest P applied. These represented average P recovery of 5.51 % after one day and 20.69 % after 240 days of incubation. The conc. HCl extracts also represent an average of more than 20 % of the total extractable soil P pool (Tables 4a-8a).

The corresponding values for the Loskop soil were lower ranging from 29.33–39.87 (1 day) to 34.83-71.08 mg kg^{-1} (240 days) for 0-200 mg kg^{-1} added P. The average P recovered was 8.69 % after 1 day and 19.22 % after 240 days of incubation. The conc. HCl-P_i extracts represent in average about 20 % of the total extractable P pool, which are roughly identical to those of the Rustenburg soil (Tables 4b-8b).

These values are relatively lower than those of Tiessen and Moir (1993) who found values of 193 mg kg^{-1} conc. HCl-P_i extracts for Chernozem (mollisol) from native prairie, and 140 mg kg^{-1} from similar soil after 65 years cultivation in Canada. But the values are higher than those of du Preez and Claassens (1999) with a highly weathered Clovelly soil that remained unchanged between about 45.3-51.5 mg P kg^{-1} after 15 years of cultivation. But, with another highly weathered Avalon soil, they found relatively very low values (19.30-7.55 mg P kg^{-1}).

The graphs in Figures 8a and b also show that for both soils C/HCl-extracted P_i increased with the increases of the added P and the increasing incubation time. The fact that these regression equation graphs were straight lines indicates that no equilibrium was reached, but longer incubation time would be required to fix sufficient amounts of the added P into this pool. The marginal changes recorded between the first and 60 days of incubation further confirms that this fraction consists of mainly the occluded and the recalcitrant P that requires some time to form.

C/HCl-extracted P_o:

According to the ANOVA in the Appendices I Nos. 8 and 20 there were significant differences in the extractable C/HCl-P_o due to the treatments applied. Here again this fraction contributed just a small part of the total soil P pool (Tables 4-8). In this P_o fraction the extractable P_o kept on increasing with increasing incubation time (Tables 2 and 3; Figs. 9a and b). This indicates that some of the added P (P_i) was evaluated with the P_o, which again may have been an experimental error in the differentiation of P_i and P_o as explained by Tiessen and Moir (1993).

3c: (ii). The effects of added P and the incubation periods on the conc. H_2SO_4 + H_2O_2–extracted P

The data for the residual P (conc. H_2SO_4 + H_2O_2-P_i) extracts of Rustenburg and Loskop soils show that the changes with different P and incubation treatments were also highly significant at 0.01 % level (Appendices I Nos. 9 and 21).

The H_2SO_4-P_i extracts of Rustenburg soil were very high and varied in values from 55.27–61.67 (1 day) to 61.83-99.17 mg kg^{-1} (240 days) between 0 and 200 mg kg^{-1} of added P. The average P recoveries were 2.96 % after one day and 17.20 % after 240 days of incubation (Table 2). This fraction represented approximately 20-25 % of the total soil P pool during the incubation period (Tables 4a-8a).

Corresponding values for the Loskop soil were lower and ranged from 39.83-45.67 (1 day) and 42.59-79.82 mg kg^{-1} (240 days) with 0-200 mg kg^{-1} added P. The average percent P recovered were 1.58 % after one day and 15.70 % after 240 days of incubation (Table 3). This fraction represented approximately 20 % of the total extracted soil P pool throughout the incubation period (Tables 4b-8b).

The graphs in Figures 10a and b are very similar to Figures 8a and b of the conc. HCl-P_i extracts. These graphs show that for both soils H_2SO_4-P_i extracts increased steadily with the increasing P additions and incubation times. Both soils showed that a fair amount of transformation to this fraction took place within 60 days. It is also evident that this pool can be a major sink for applied P because in both soils there were steady increases in this pool with increased incubation times.

The contributions of H_2SO_4-P_i extracts to the total extracted soil P pool were as high as those from the –OH-P_i and the conc. HCl-P_i fractions for both soils. However, they also decreased with the added P levels like the conc. HCl-P_i (indicating that transformations of the added P into the pool was low) and similarly increased with the increasing days of incubation (Tables 4-8). These tables also show that both soils gained more or less equal amounts of H_2SO_4-P_i with the added P levels throughout the incubation period.

These findings are comparable to those of Bowman et al. (1998) who also found an average of about 26 % of the total soil P pool was resistant P. But the more weathered soils from the tropics contained about 50 % resistant P or residual P. Similarly du Preez and Claassens (1999) also reported that the H_2SO_4-P_i fraction represented 44.1-48.6 % (Avalon) and 51.1-59.4 % (Clovelly) of the total soil P pool.

Chang and Jackson (1957) had reported that the residual fraction consisted mainly of Fe-and Al-P, and the proportions of each depended on pH, total amounts of P, ages of soils, and degrees of weathering. The amounts of residual P were highest in the samples from the oldest soils that were studied. Further, Oades and Ladd (1977) reported that as much as one quarter of P in the bacterial cells were non-extractable from soil. They concluded that it was possible that during the incubation processes the bacterial population increased, and that could have resulted in the slow accumulation of residual P.

Further they suggested that the majority of P_o forms in the residual P_o (H_2SO_4-extracts) are of larger molecular weights that correspond to the humic and fulvic acid fractions, which are stable, and not subject to much mineralization over time. Dalal (1977) had also reported that phosphorus held in organic form could be fixed into some insoluble form and become occluded or residual.

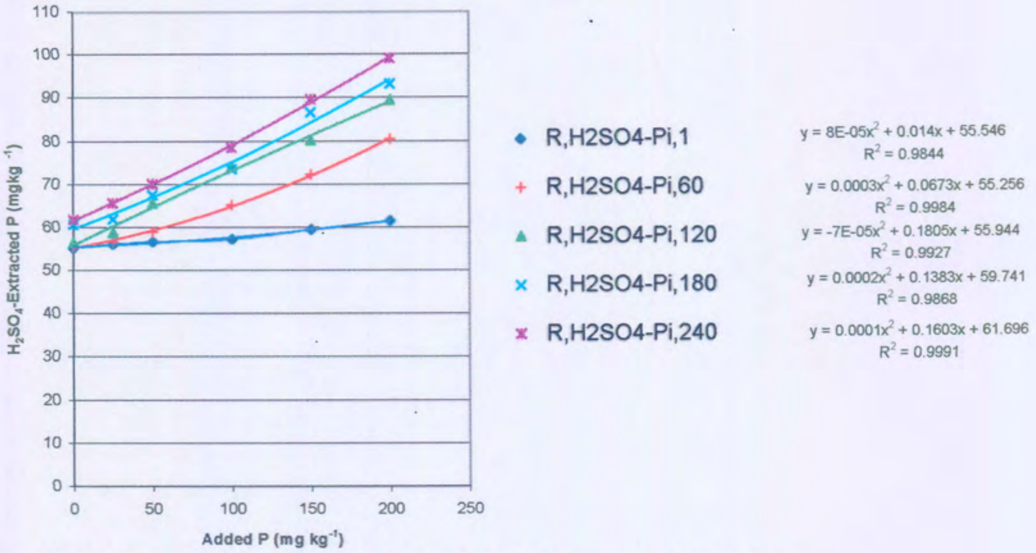

Fig. 10a. The effects of the added P and incubation time on the concentrated sulphuric acid (H_2SO_4) extracted residual P (P_i) from the Rustenburg soil.

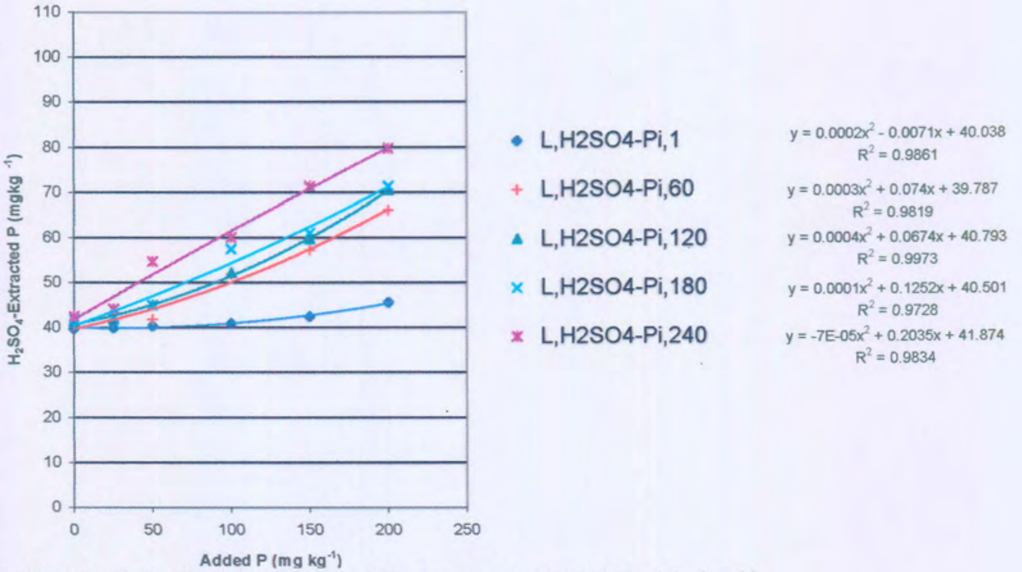

Fig. 10b. The effects of the added P and incubation time on the concentrated sulphuric acid (H_2SO_4) extracted residual P (P_i) from the Loskop soil.

Total insoluble P: Occluded and residual P (conc. HCl- and H_2SO_4 + H_2O_2-P_i –extracts)

The proportion of the total soil P extracted in the insoluble P (C/HCl-P_i + H_2SO_4-P_i) pool represented 44.24 % (1 day) and 51 % (240 days) for Rustenburg, and 36 % (1 day) and 43.34 % (240 days) for Loskop soil (Tables 4-8). These results show that the largest proportion of the total soil P pools in both soils consists mainly of relatively insoluble P_i (occluded and residual P) forms and stable humus and humic acids. The effects of incubation on the applied P of both soils resulted in accumulation of P in pool.

4. The effectiveness and limitations of the methodologies used

The resin strips technique in the Tiessen and Moir (1993) method was replaced by a new desorption technique developed by Freese et al. (1995) that is based upon the use of hydrous ferric oxide (HFO) as a sink for P. Instead of being impregnated in filter paper, the HFO is present inside dialysis membrane tubing (DMT). The membrane seemed to have provided excellent means to separate the soil suspension from the P sink. The DMT-HFO system was mechanically stable during the course of the experiments, and practically no HFO passed through the membrane. After each desorption step, the sink was easily separated from the soil suspension with very minimal or no loss of soil materials. As such, the new technique showed important advantages over the resin strips method.

However, since the P_o extracted as $-HCO_3$-P and –OH-P were determined by the difference between P_t and P_i in each extract, there was an inherent source of error. The P_i was determined in the supernatant after precipitation of organic matter with acid, and any P_i that precipitated along with the organic matter could have caused an error in the calculation of P_o (P_t-P_i). This is reported to occur with P_i associated with Fe and Al oxihydroxides, which are soluble at high, but insoluble at low pH. It has so far not been possible to quantify the P_o overestimation. This could have resulted in the relatively higher levels of P_o extracted from the Rustenburg and Loskop soils.

However, this fractionation approach is reported to be currently the only one that can be used with moderate success for the evaluation of available P_o. According to Tiessen and Moir (1993), the original fractionation of Hedley et al. (1982) left between 20 and 60 % of the P in the soil un-extracted. This residue often contained significant amounts of P_o that sometimes participated in relatively short-term transformations. As a whole the sequential P extraction procedures proved very effective. The amounts extracted varied from 96-107 % and 95-104 % of the expected total P from Loskop and Rustenburg soils respectively.

CONCLUSIONS

In a study to investigate the fate of the applied P to 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), a DMT-HFO extraction procedure was used to extract P from the treated soils. The subsequent sequential fractionations to determine the P content of the different P pools gave an indication as to which pool the applied P was transformed into. The two soils were treated to different P rates (0, 25, 50, 100, 150, and 200 mg kg^{-1}), and incubated for 1, 60, 120, 180, and 240 days under a laboratory conditions. The sequential P fractionation procedure determined, (a) plant-available P: DMT-HFO-P (solution P_i) and 0.5M $NaHCO_3$-P (labile P_i and P_o); (b) adsorbed P: 0.1M NaOH-P (Al-, Fe- oxihydroxide-P_i and P_o) and 1.0M HCl-P (apatite/Ca-bound-P_i); (c) insoluble and residual P: conc. HCl-P (occluded/insoluble-P_i and P_o) and conc. H_2SO_4 + H_2O_2-P (residual/lattice-P_i and P_o) soil P pools.

The sequential P extractions identified the P quantities in the different P pools after different incubation periods, and how much of the added P could be recovered. In total nearly 100 % of the added P could be extracted through the different extractions. The percent P in each fraction changed with time of incubation. Between 20 and 30 %, and 20 and 35 % of the P could be extracted with DMT-HFO 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 form after 1 day. Within 60 days 80-90 % of the added P was transformed to the less labile P pools. This transformation was faster in the Rustenburg than the Loskop soil showing a higher P fixation capacity. 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. The Loskop soil had more marked increases in solution and labile P than the Rustenburg soil, while the Rustenburg soil showed higher values for the adsorbed, occluded and residual P forms. The noted differences could explain the reportedly higher levels of P fixation (adsorption and/or precipitation) by the Rustenburg soil than by the Loskop soil. It should also be noted that increasing levels of applied P did not correspondingly increase the percent recovery of labile P in both soils.

It may 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. This therefore, formed the basis for the experiments reported in Chapter 3.

To maximize fertilizer P efficiency especially in the Rustenburg soil, band placement at planting time should be recommended, as the findings show that after 1 day of incubation 60 % of the added P was transformed into less labile P. When band placed the soil in the vicinity of the band will be saturated with P and some P will remain in more labile form and thus available for a longer period of time. The use of plants with well-developed root systems could also be recommended to ensure that it explores the soil volume more effectively.

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 ^{0}C (+ or - 2 ^{0}C). 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_i	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	21.46	27.63	32.54	35.27	42.30
HCO_3-P_i	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	16.65	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	4.46	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_i	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_i	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_i	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
$H_2SO_4P_i$	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_i	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	58.30	62.83	30.46	35.88	41.15	44.88	50.59
HCO_3-P_i	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	25.46	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_i	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_i	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_i	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	5.46	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
$H_2SO_4P_i$	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	267.83
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	8.68	6.08	4.54	5.46	10.61	7.68	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
$H_2SO_4P_i$	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	13.65	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	6.27	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	78.60	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
$H_2SO_4P_i$	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	98.95	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	7.93	6.90	5.61	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	16.80	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	16.40	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	6.36	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
$H_2SO_4P_i$	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	88.67	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	2.88
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	16.88	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	5.60	5.14	4.46	4.13	3.66	3.04	2.84	2.50	2.84	2.80
$H_2SO_4P_i$	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	15.96
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

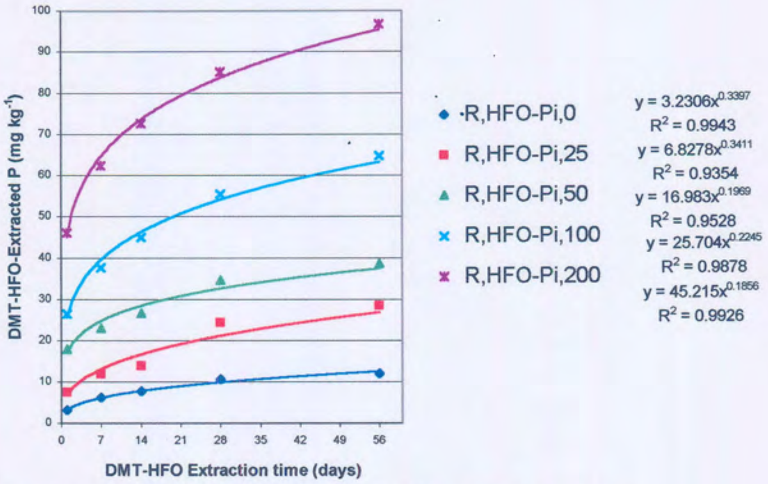

Fig.1a. The effects of the added P on cumulative DMT-HFO extractable P_i after 1 day of incubation of Rustenburg soil

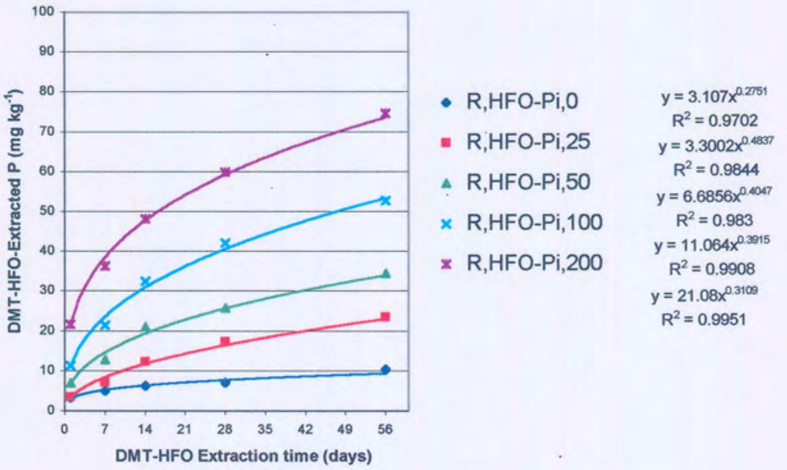

Fig.1b. The effects of the added P on cumulative DMT-HFO extractable P_i after 120 days of incubation of Rustenburg soil

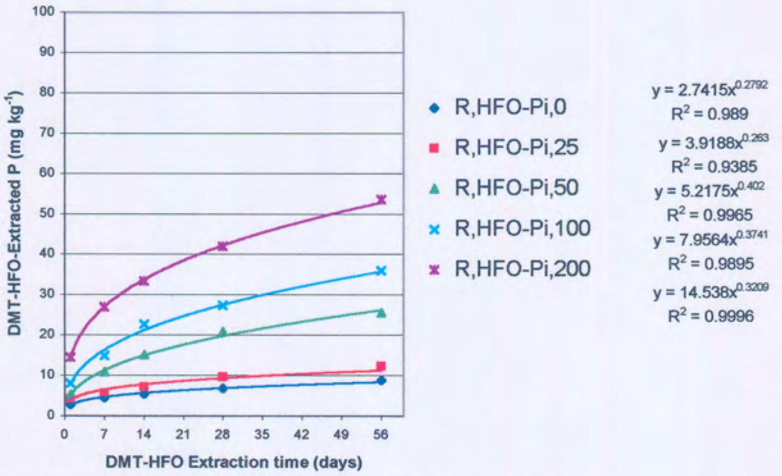

Fig.1c. The effects of the added P on cumulative DMT-HFO extractable P_i after 240 days of incubation of Rustenburg soil

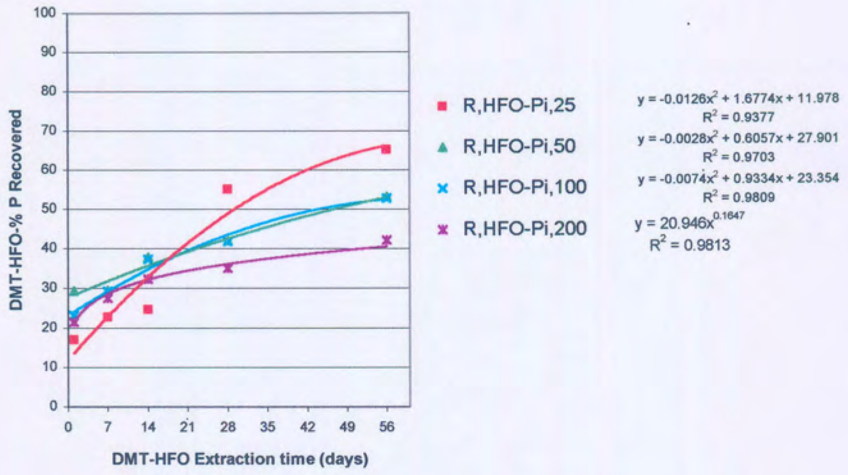

Fig.1.1a. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 1 day of incubation of Rustenburg soil

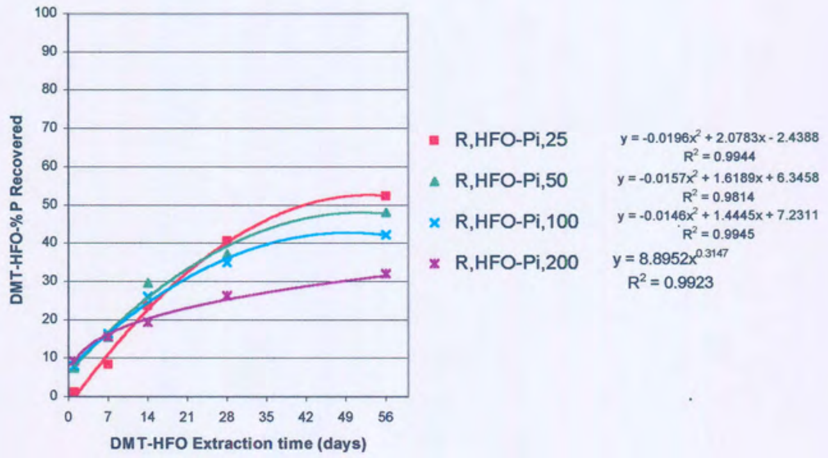

Fig.1.1b. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 120 days of incubation of Rustenburg soil

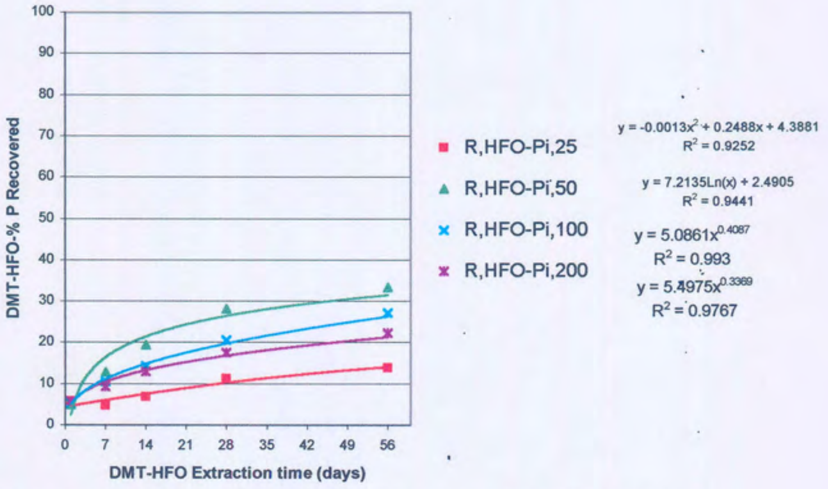

Fig. 1.1c. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 240 days of incubation of Rustenburg soil

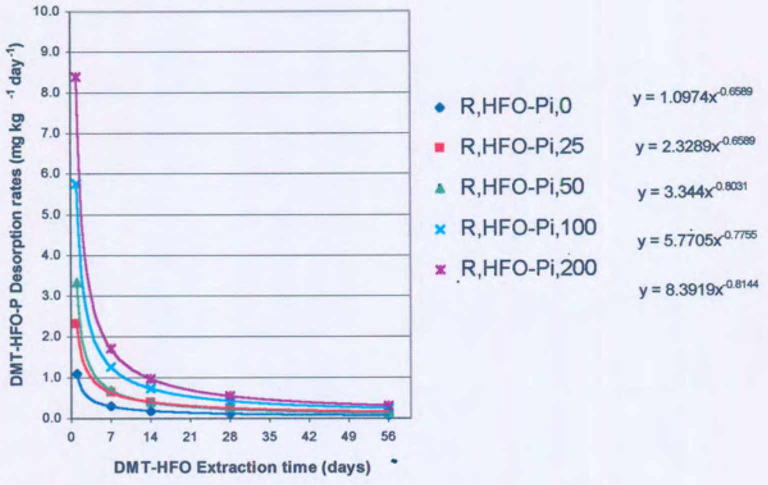

Fig. 1.2a. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 1day of incubation of Rustenburg soil

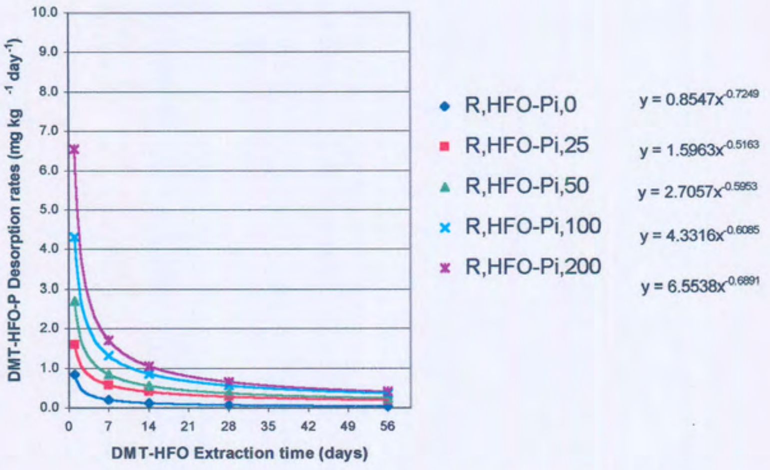

Fig.1.2b. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

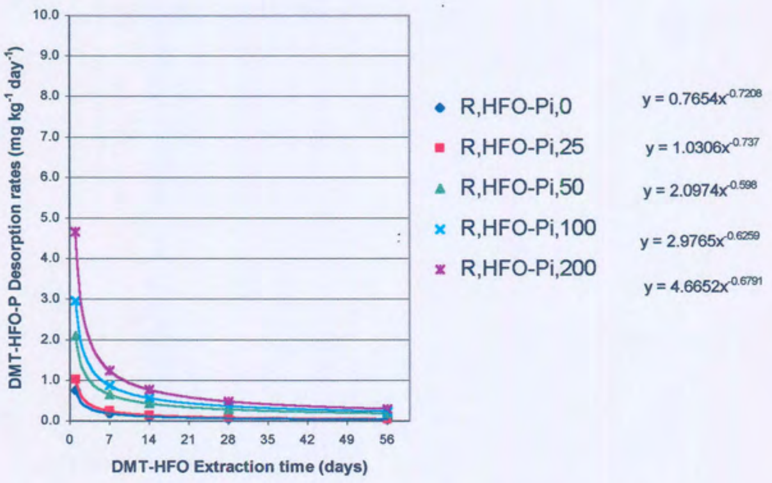

Fig. 1.2c. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

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).

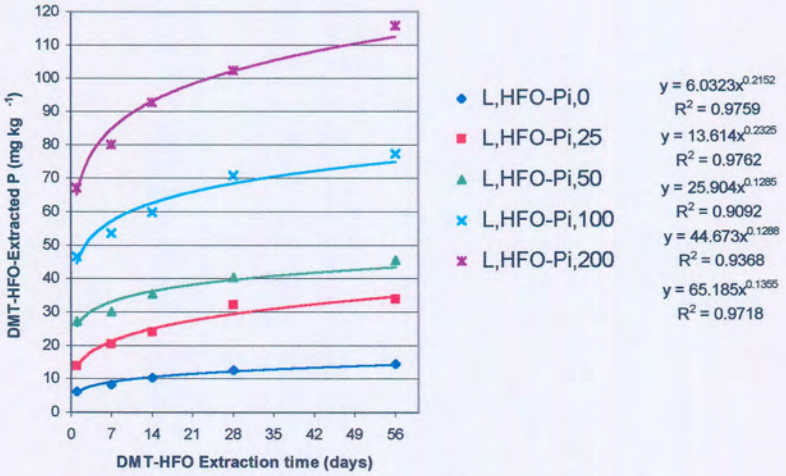

Fig. 2a. The effects of the added P on cumulative DMT-HFO extractable P_i after 1 day of incubation of Loskop soil

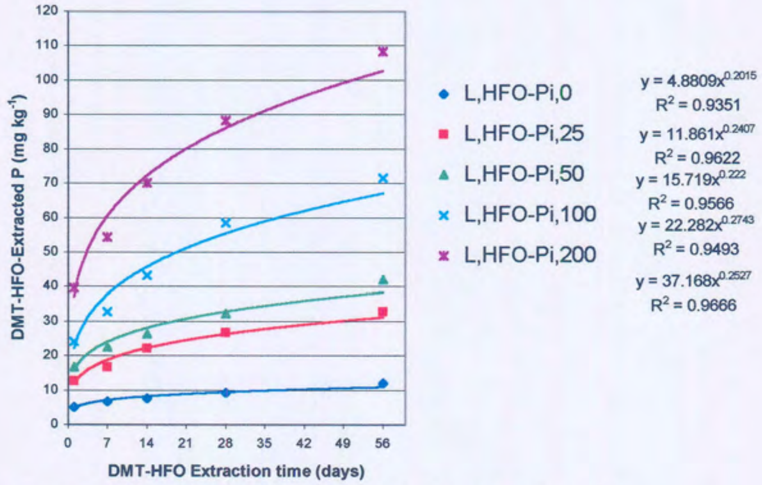

Fig. 2b. The effects of the added P on cumulative DMT-HFO extractable P_i after 120 days of incubation of Loskop soil

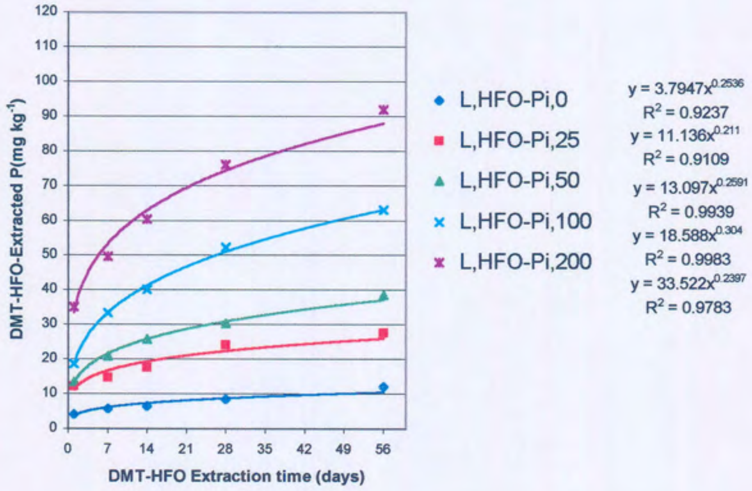

Fig. 2c. The effects of the added P on cumulative DMT-HFO extractable P_i after 240 days of incubation of Loskop soil

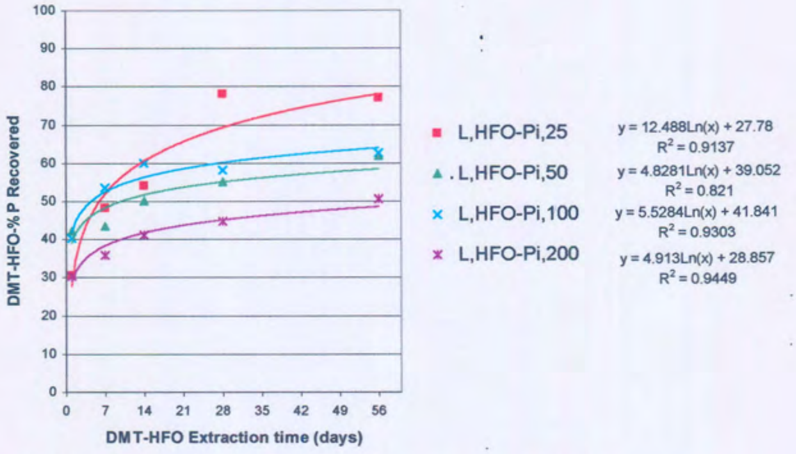

Fig. 2.1a. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 1 day of incubation of Loskop soil

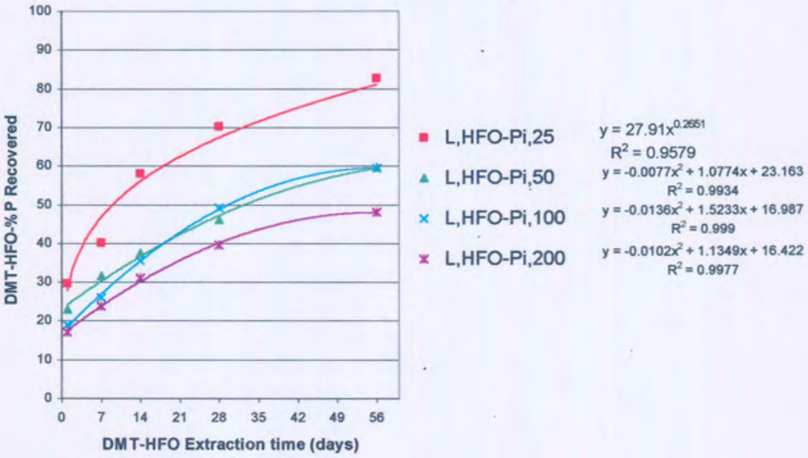

Fig. 2.1b. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 120 days of incubation of Loskop soil

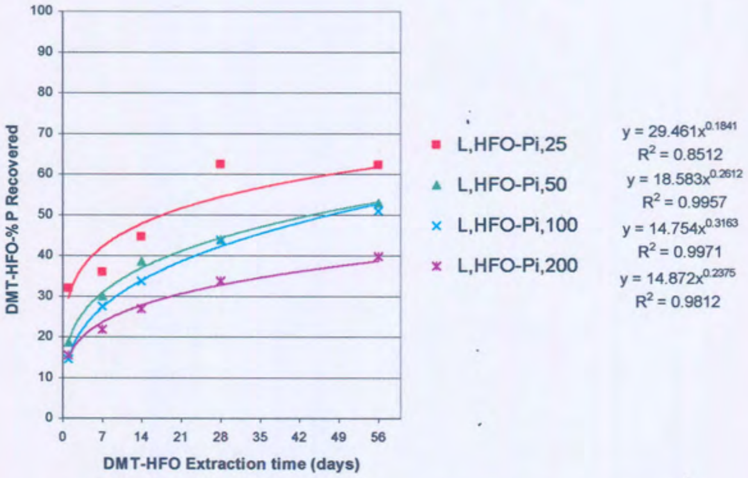

Fig. 2.1c. The effects of the added P on percentage P recovered with DMT-HFO-P extractions after 240 days of incubation of Loskop soil

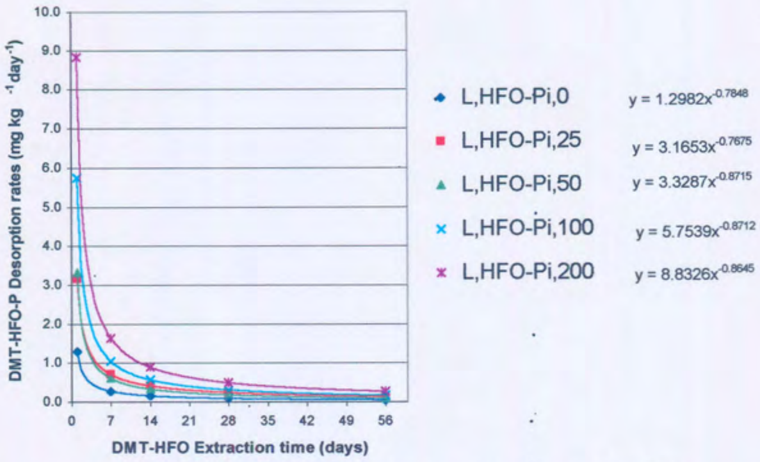

Fig. 2.2a. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

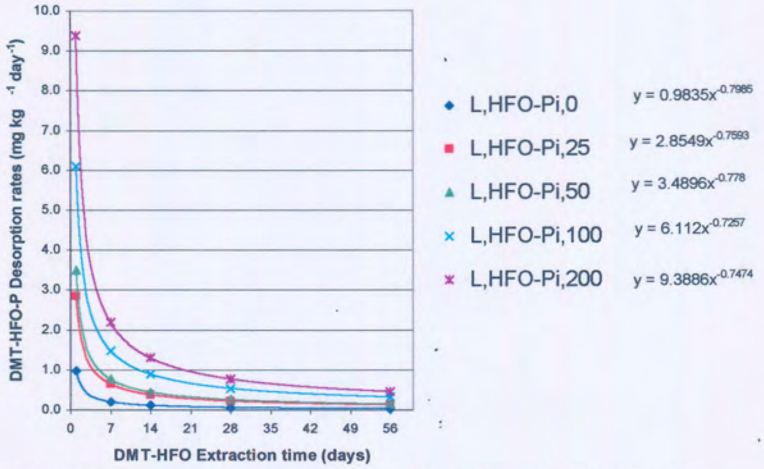

Fig. 2.2b. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

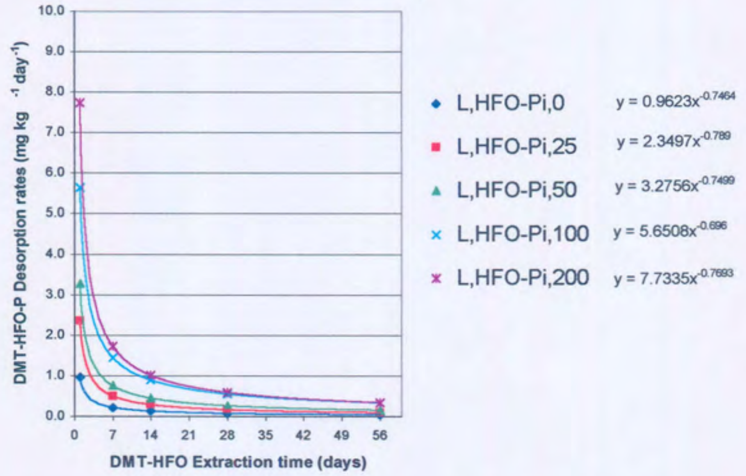

Fig. 2.2c. The effects of the added P on DMT-HFO-P desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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$_2$SO$_4$-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$_2$SO$_4$-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$_2$SO$_4$-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$_2$SO$_4$-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$_2$SO$_4$-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$_2$SO$_4$-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 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 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 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 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 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	

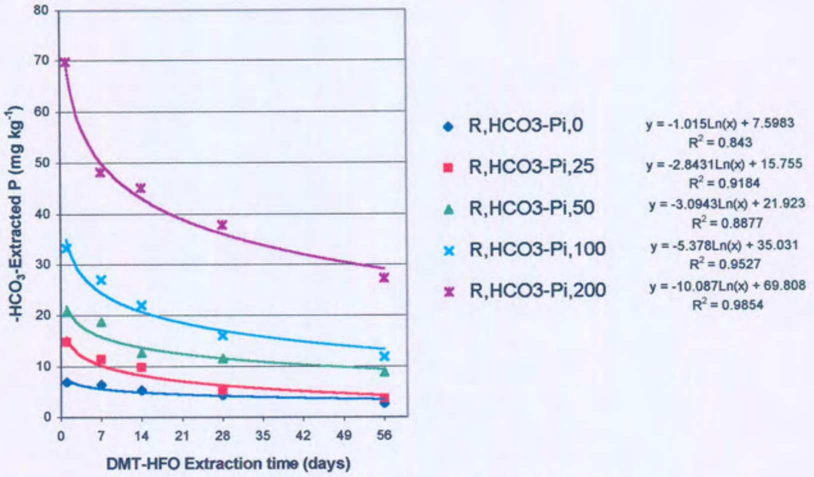

Fig. 3a. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 1 day of incubation of Rustenburg soil

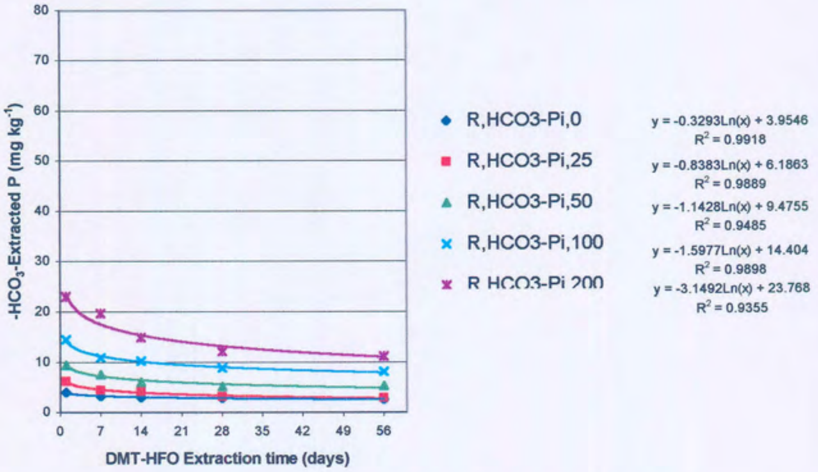

Fig. 3b. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 120 days of incubation of Rustenburg soil

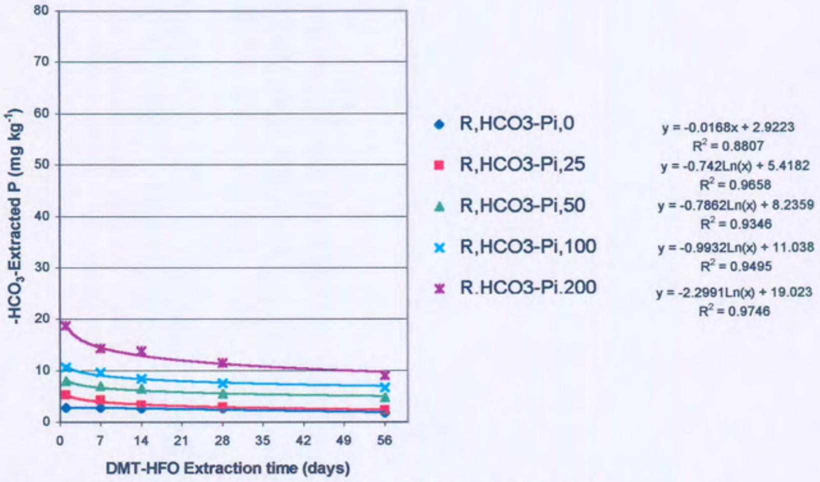

Fig. 3c. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 240 days of incubation of Rustenburg soil

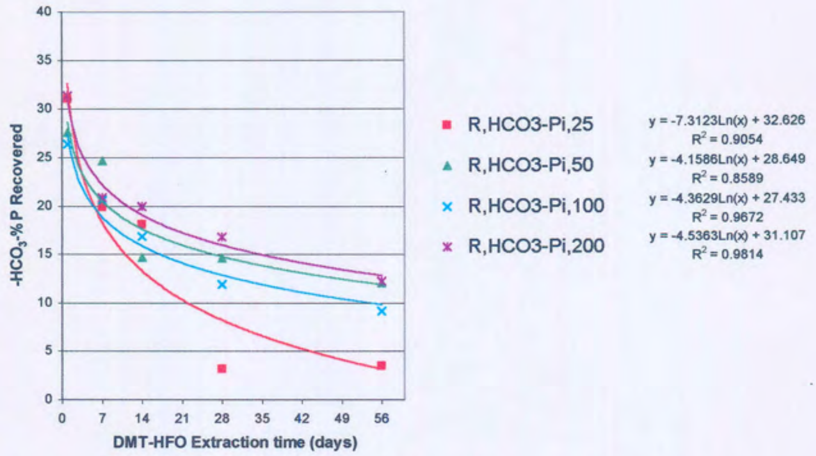

Fig. 3.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 1 day of incubation of Rustenburg soil

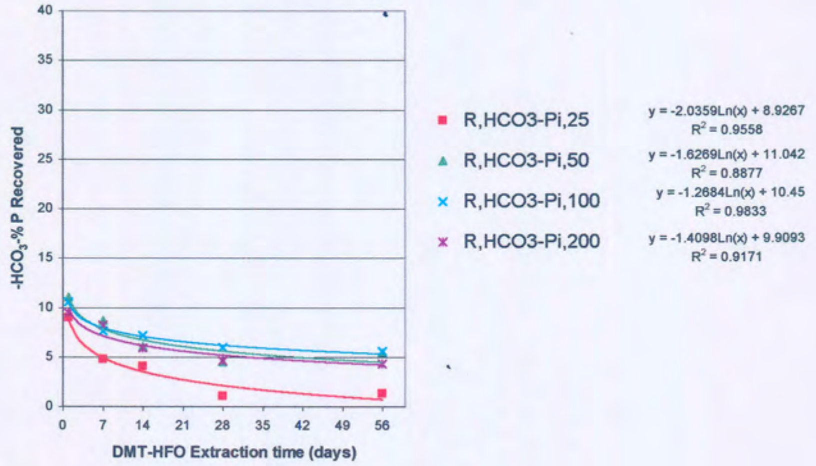

Fig. 3.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 120 days of incubation of Rustenburg soil

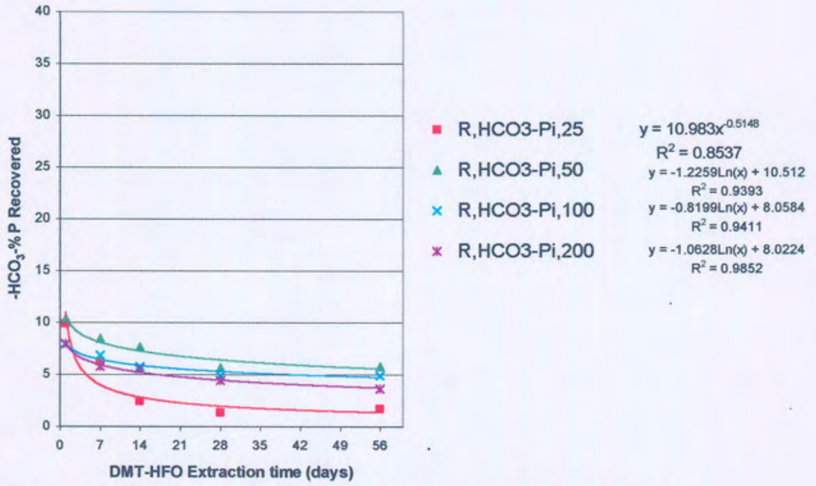

Fig. 3.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 240 days of incubation of Rustenburg soil

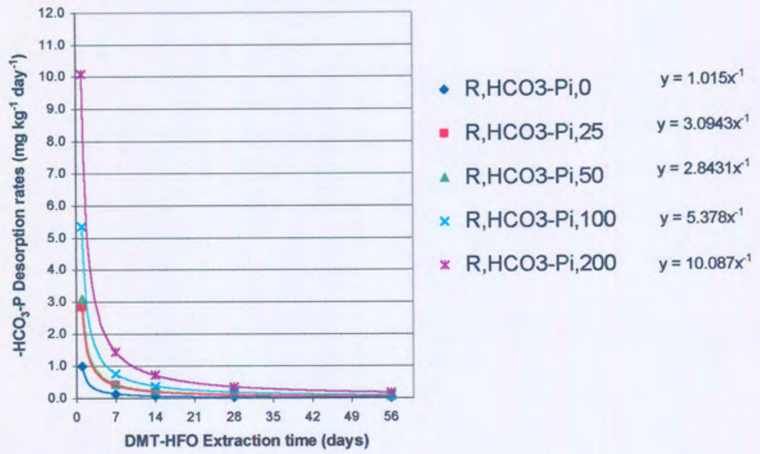

Fig. 3.2a. The effects of the added P and DMT-HFO extractions on -HCO$_3$-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

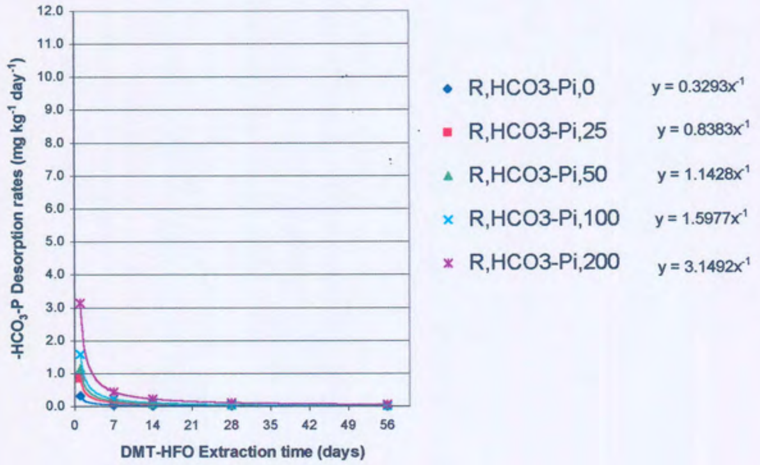

Fig. 3.2b. The effects of the added P and DMT-HFO extractions on -HCO$_3$-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

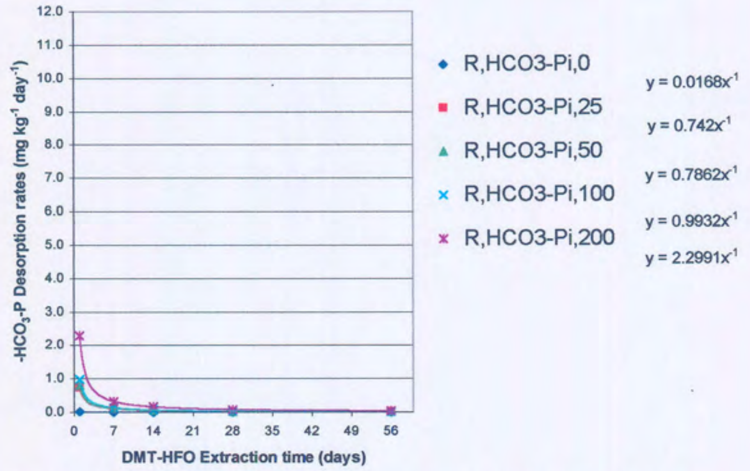

Fig. 3.2c. The effects of the added P and DMT-HFO extractions on -HCO$_3$-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

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

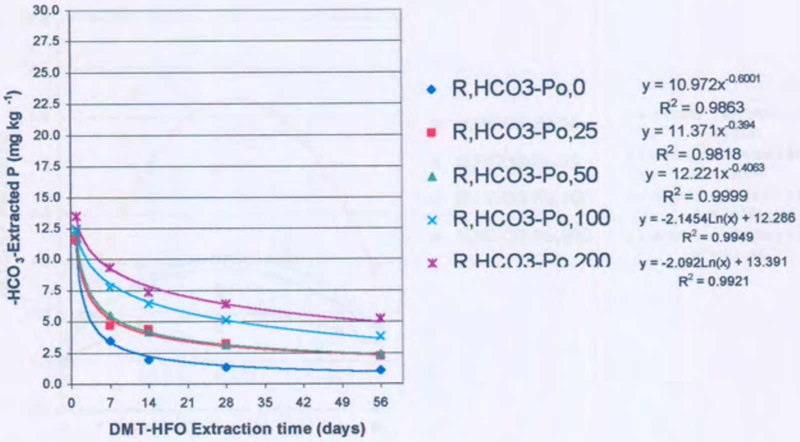

Fig. 4a. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 1 day of incubation of Rustenburg soil

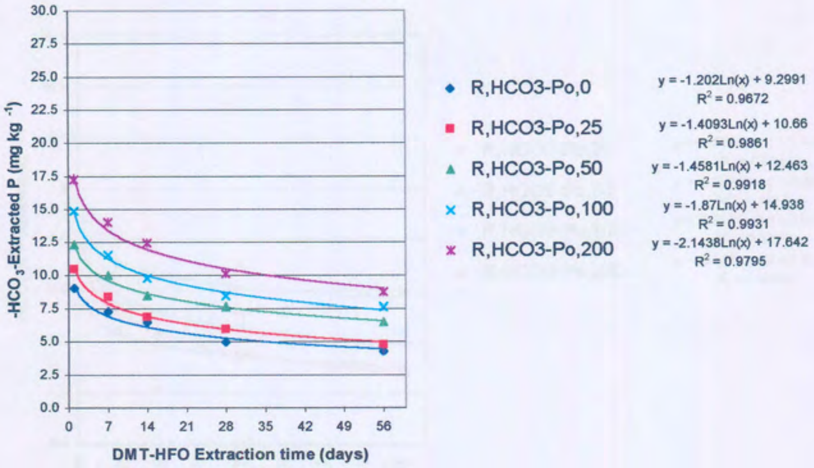

Fig. 4b. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 120 days of incubation of Rustenburg soil

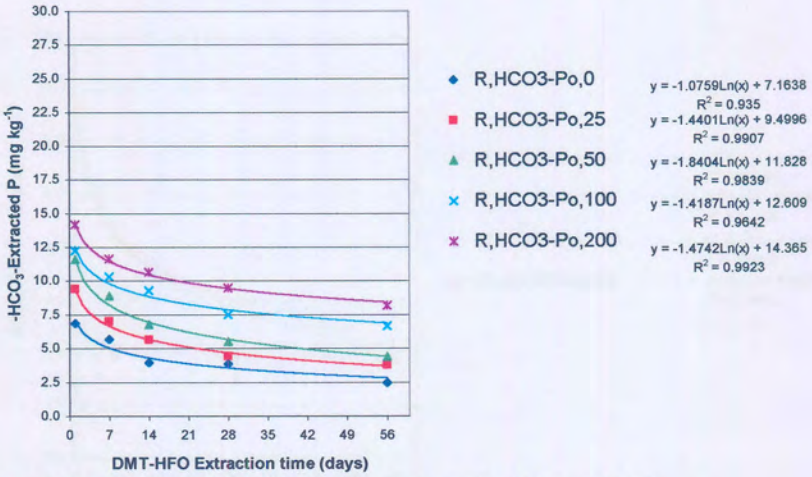

Fig. 4c. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 240 days of incubation of Rustenburg soil

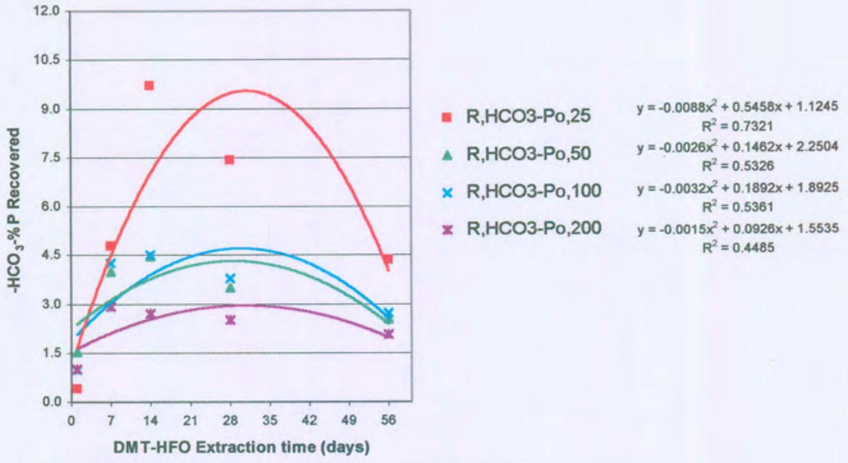

Fig. 4.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 1 day of incubation of Rustenburg soil

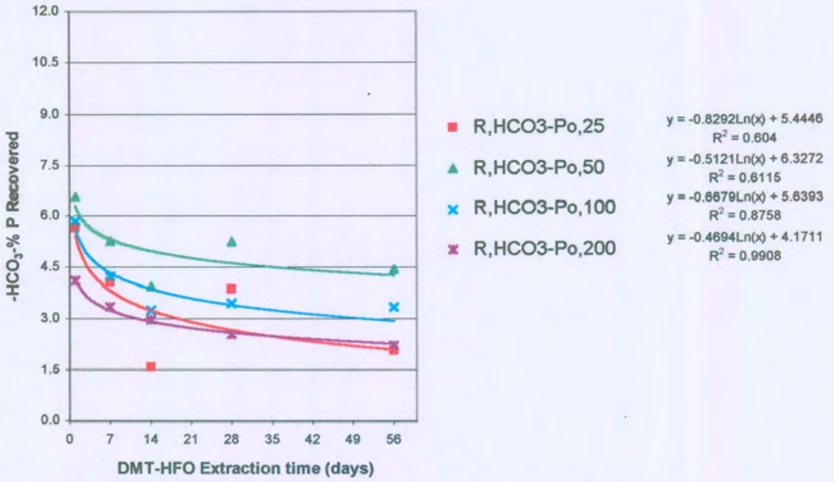

Fig. 4.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 120 days of incubation of Rustenburg soil

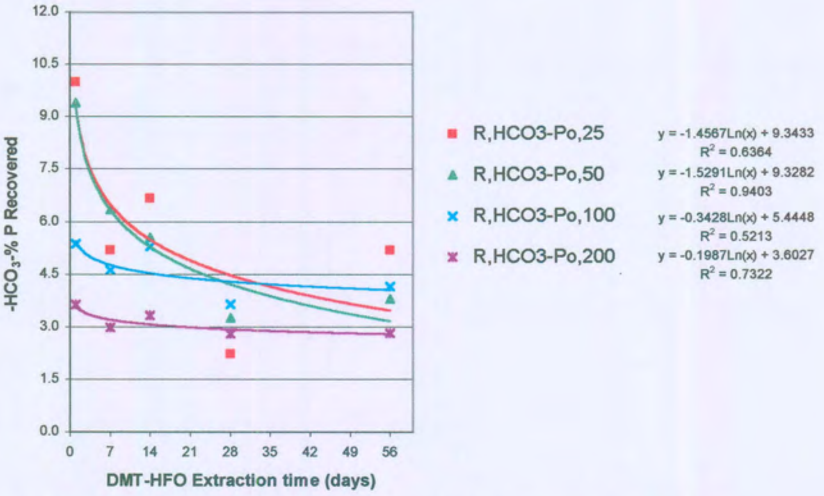

Fig. 4.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 240 days of incubation of Rustenburg soil

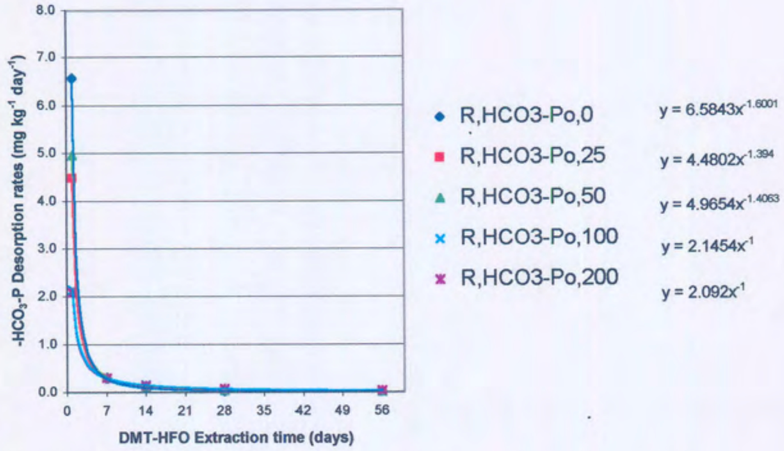

Fig. 4.2a. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

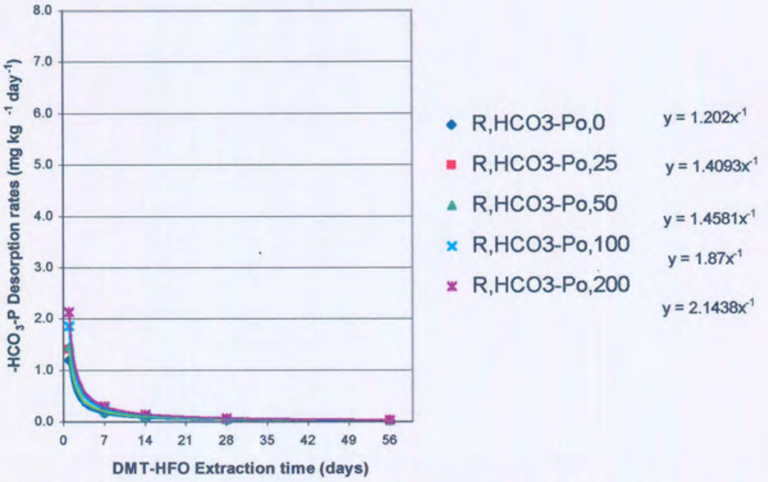

Fig. 4.2b. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

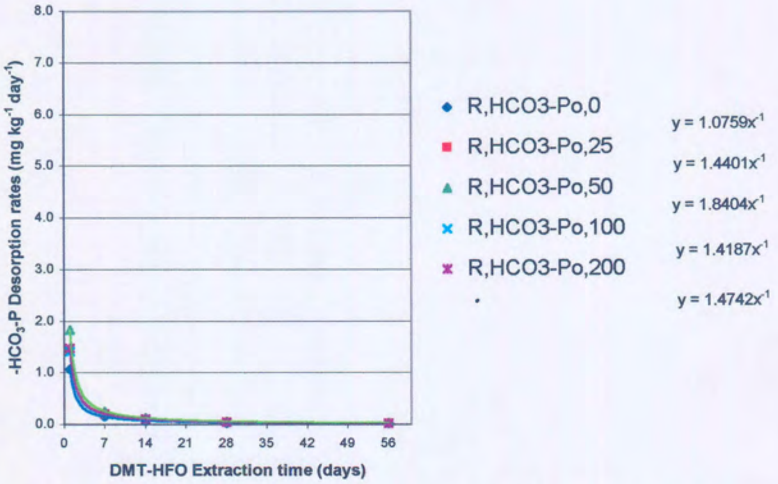

Fig. 4.2c. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

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

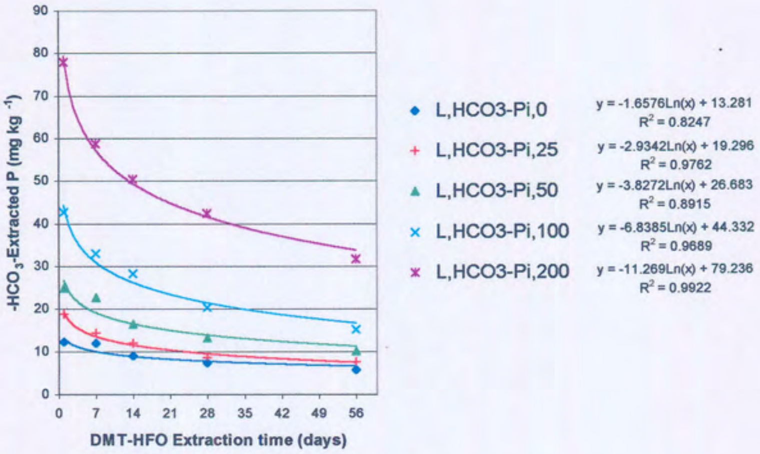

Fig. 5a. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 1 day of incubation of Loskop soil

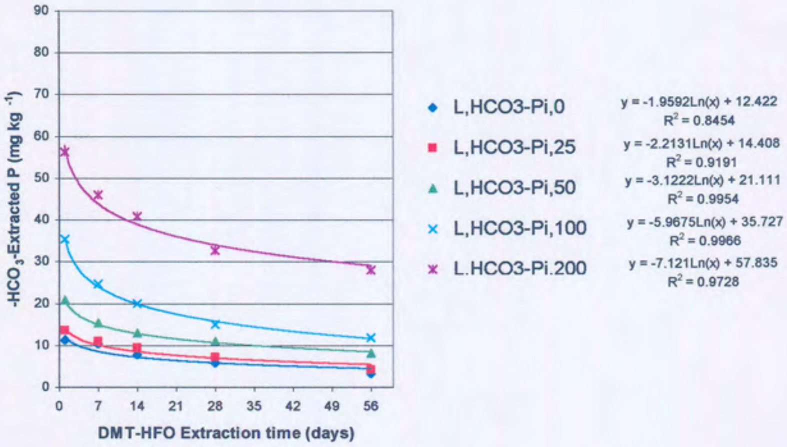

Fig. 5b. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 120 days of incubation of Loskop soil

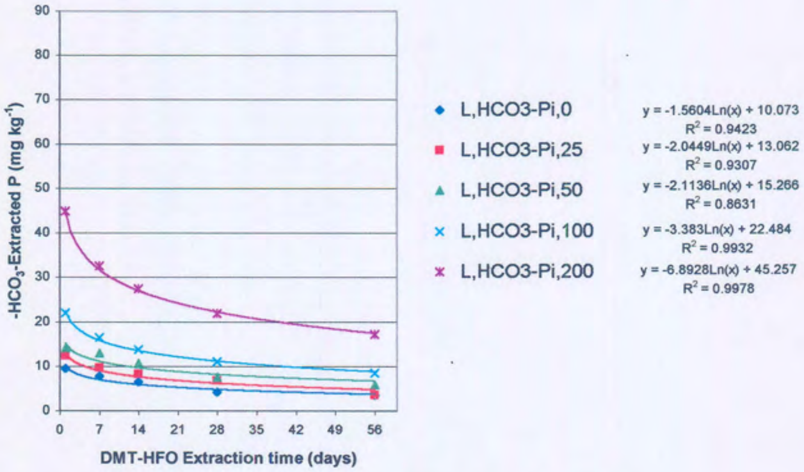

Fig. 5c. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_i$ after 240 days of incubation of Loskop soil

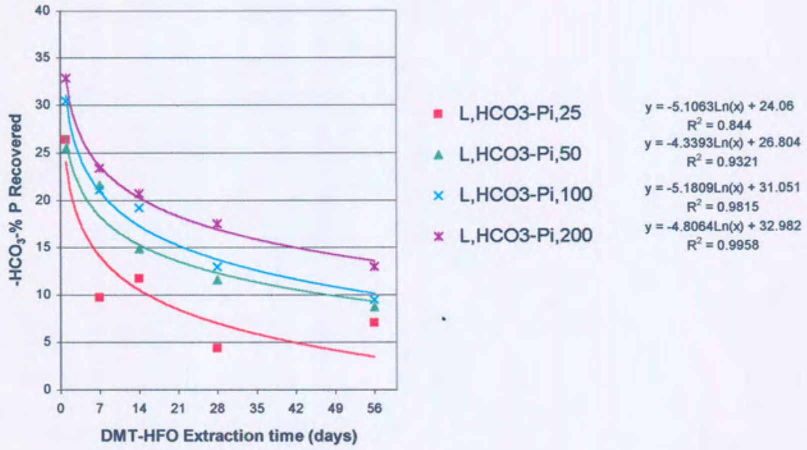

Fig. 5.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 1 day of incubation of Loskop soil

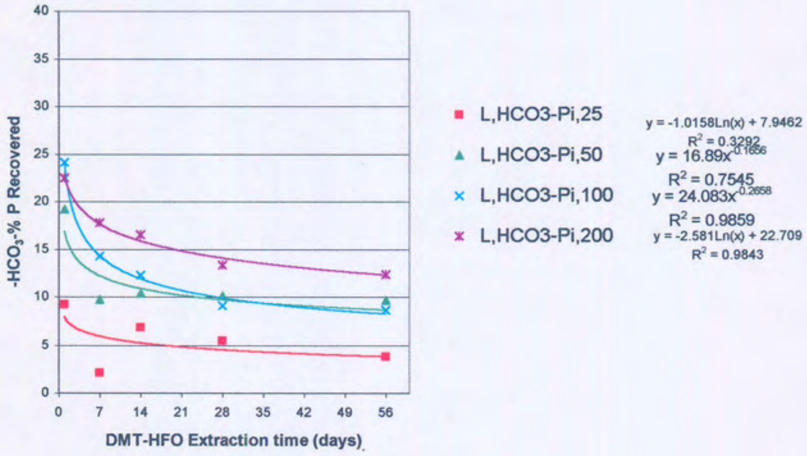

Fig. 5.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 120 days of incubation of Loskop soil

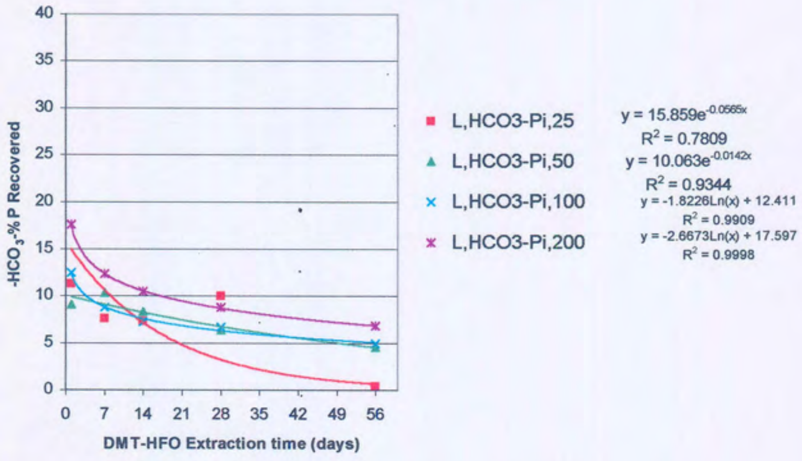

Fig. 5.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -HCO_3-P extractions after 240 days of incubation of Loskop soil

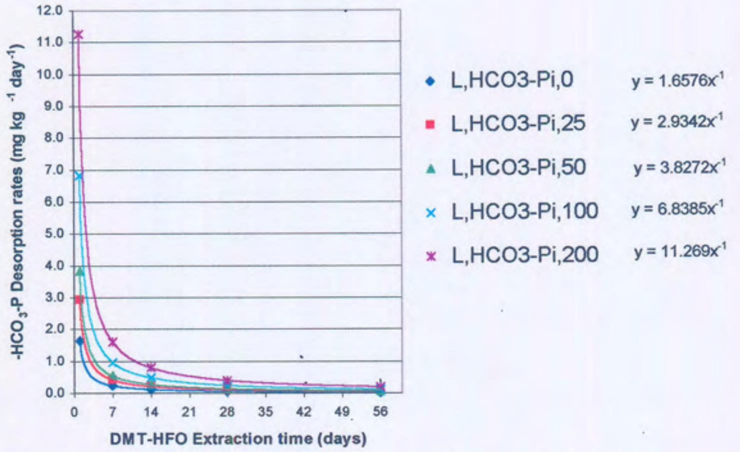

Fig.5.2a. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

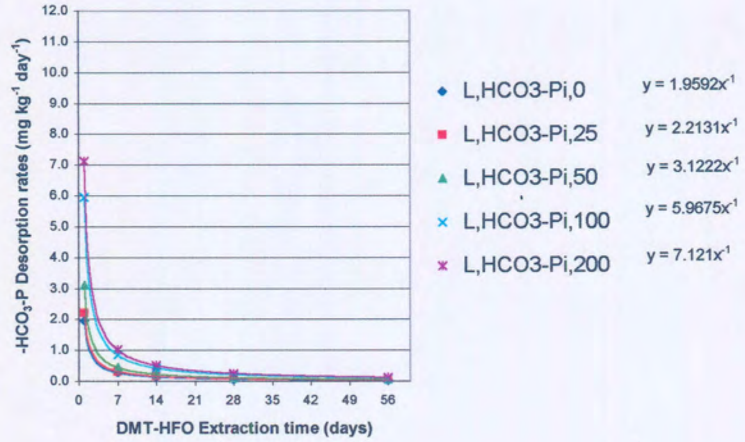

Fig. 5.2b. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

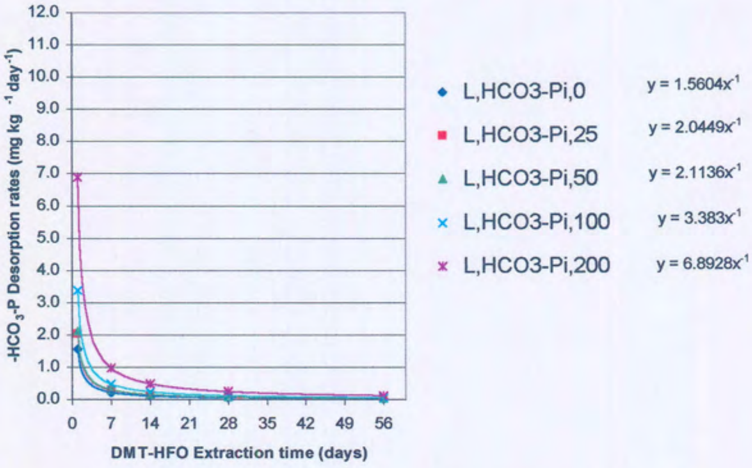

Fig. 5.2c. The effects of the added P and DMT-HFO extractions on -HCO_3-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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.

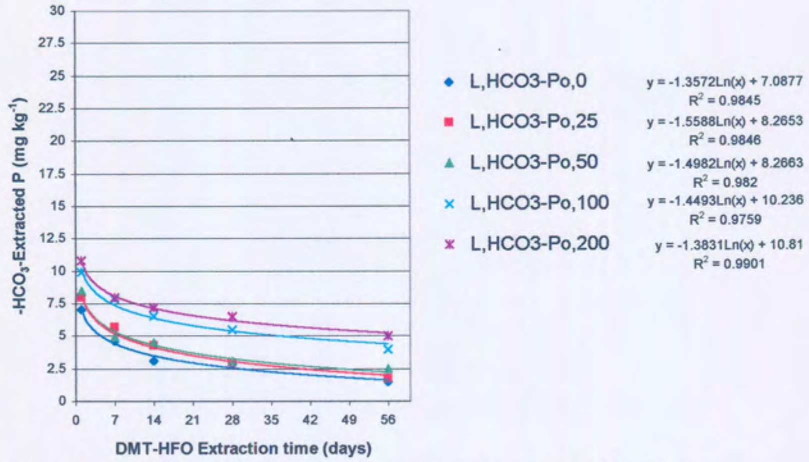

Fig. 6a. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 1 day of incubation of Loskop soil

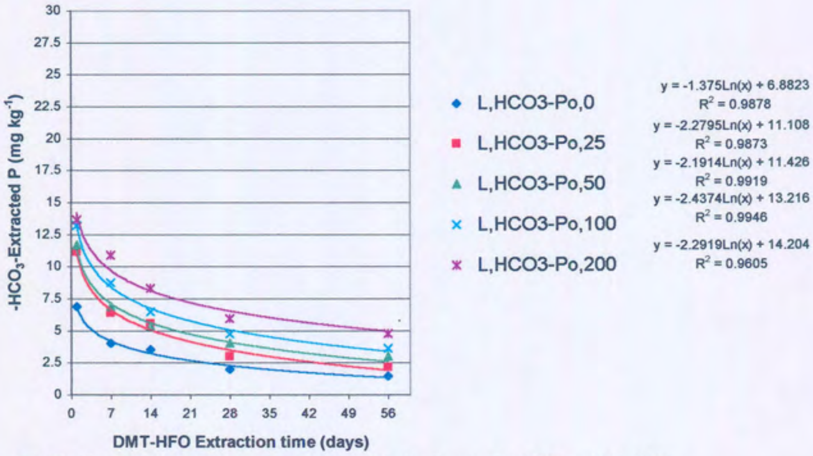

Fig. 6b. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 120 days of incubations of Loskop soil

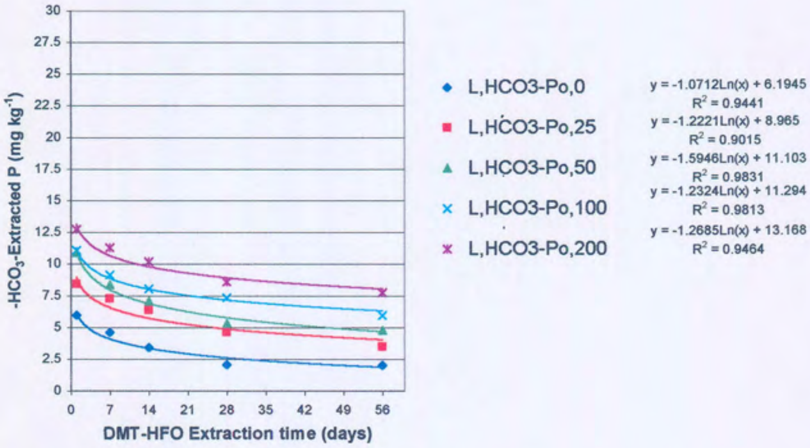

Fig. 6c. The effects of the added P and DMT-HFO extractions on the -HCO$_3$-extractable P$_o$ after 240 days of incubation of Loskop soil

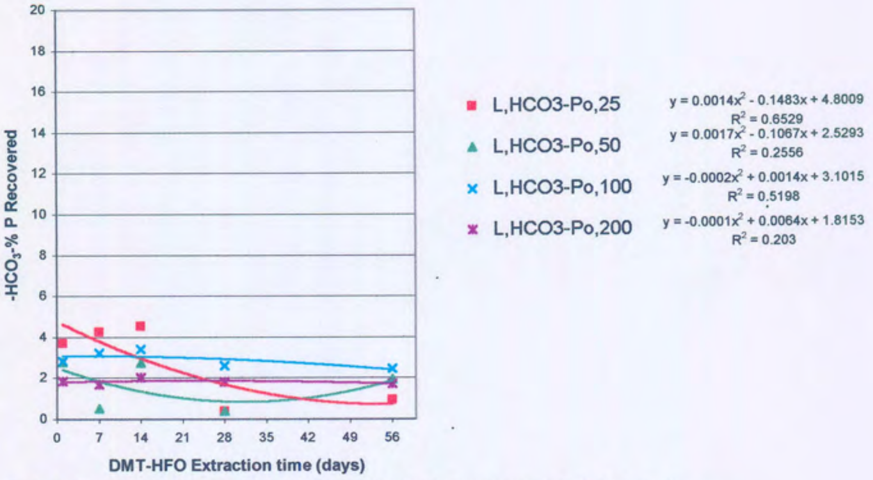

Fig. 6.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 1 day of incubation of Loskop soil

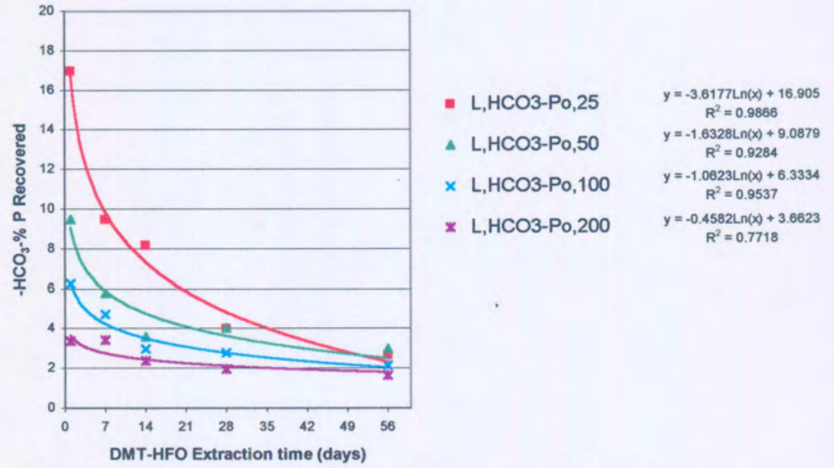

Fig. 6.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 120 days of incubation of Loskop soil

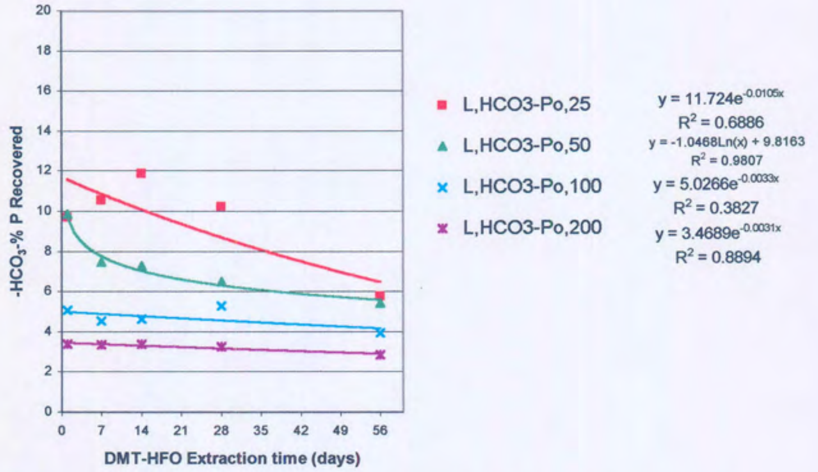

Fig. 6.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with $-HCO_3$-P extractions after 240 days of incubation of Loskop soil

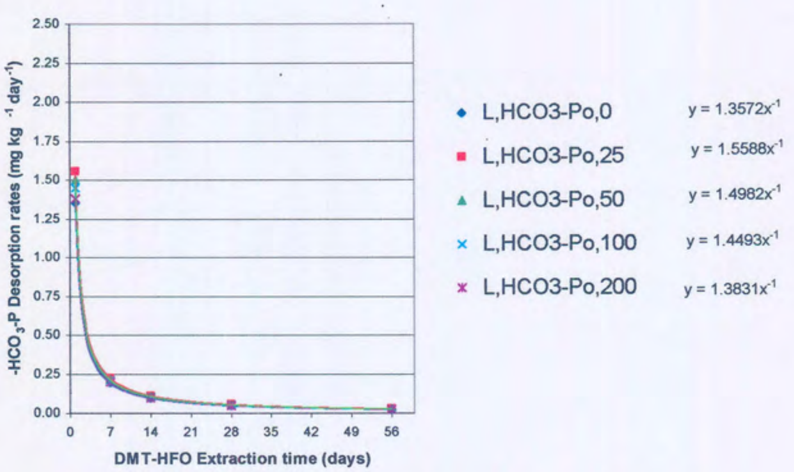

Fig. 6.2a. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

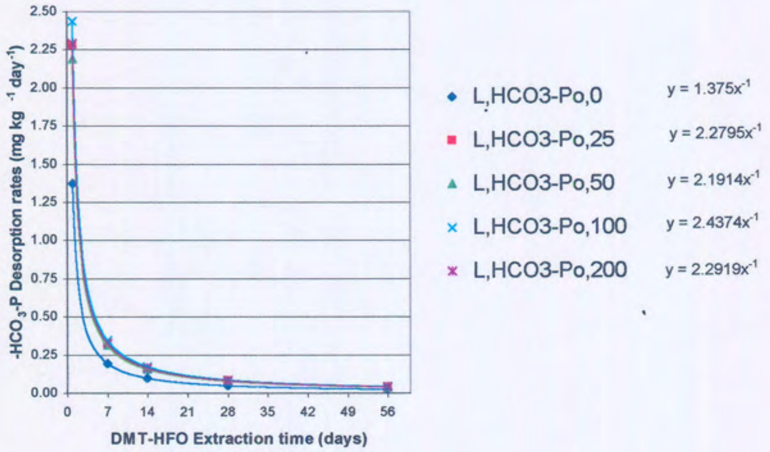

Fig. 6.2b. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

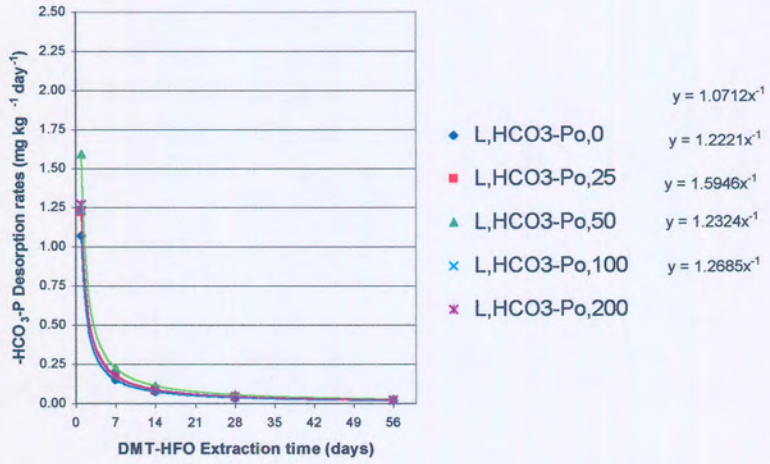

Fig. 6.2c. The effects of the added P and DMT-HFO extractions on $-HCO_3$-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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.

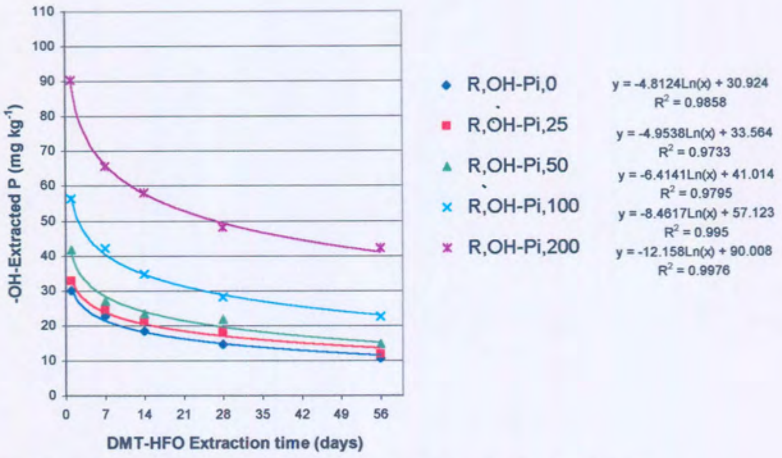

Fig. 7a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 1 day of incubation of Rustenburg soil

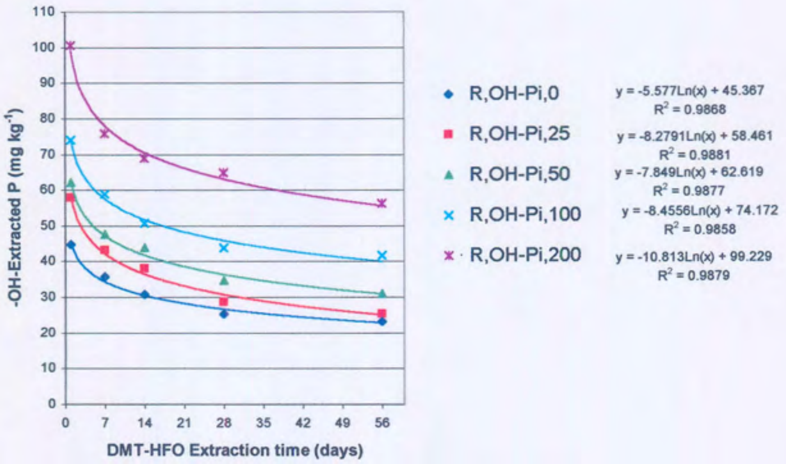

Fig. 7b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 120 days of incubation of Rustenburg soil

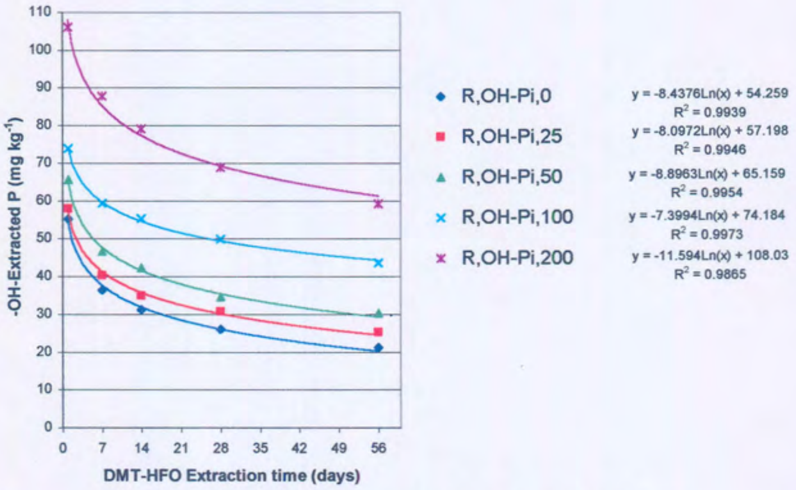

Fig. 7c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 240 days of incubation of Rustenburg soil

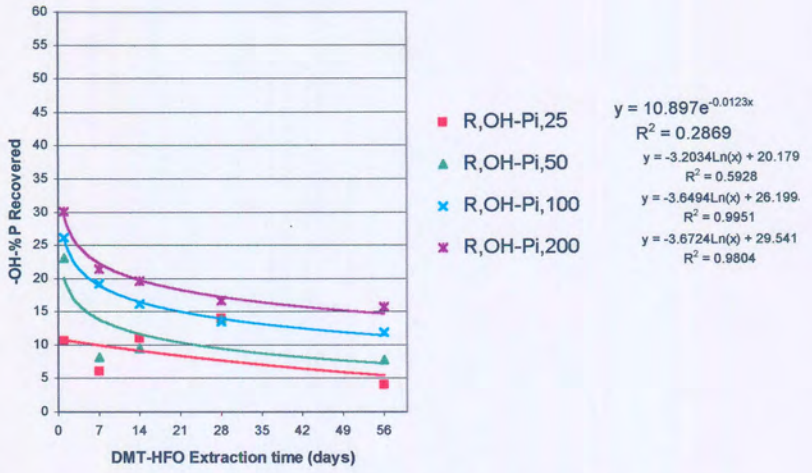

Fig. 7.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 1 day of incubation of Rustenburg soil

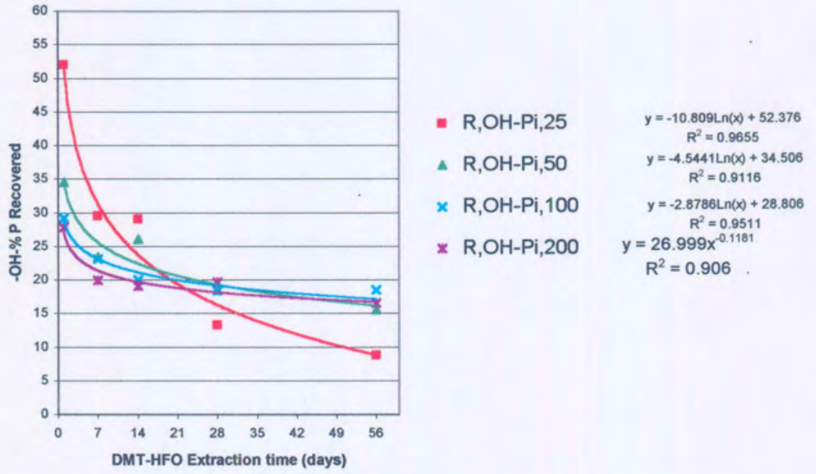

Fig. 7.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered

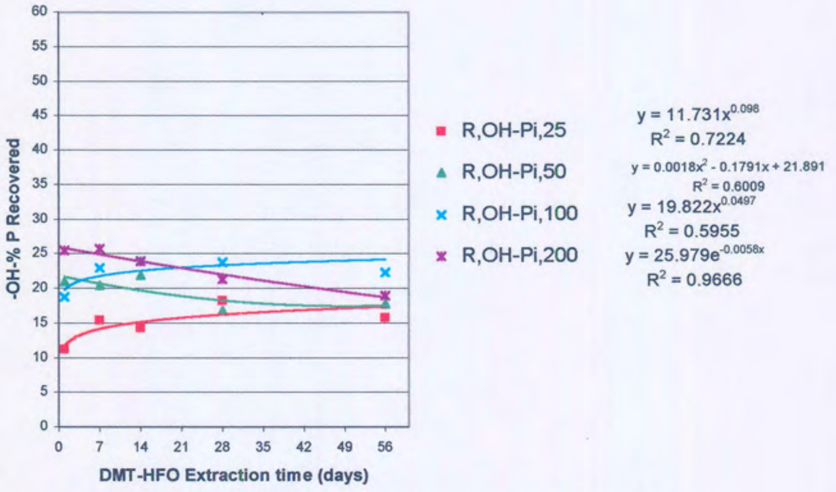

Fig. 7.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered

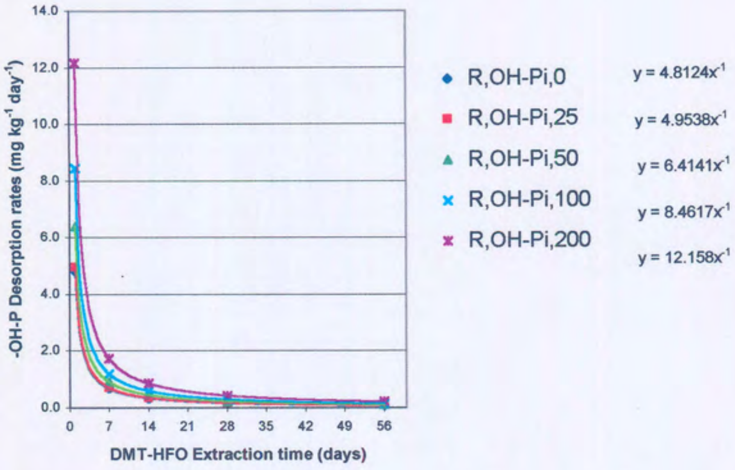

Fig. 7.2a. The effects of the added P and DMT-HFO extractions on -OH-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

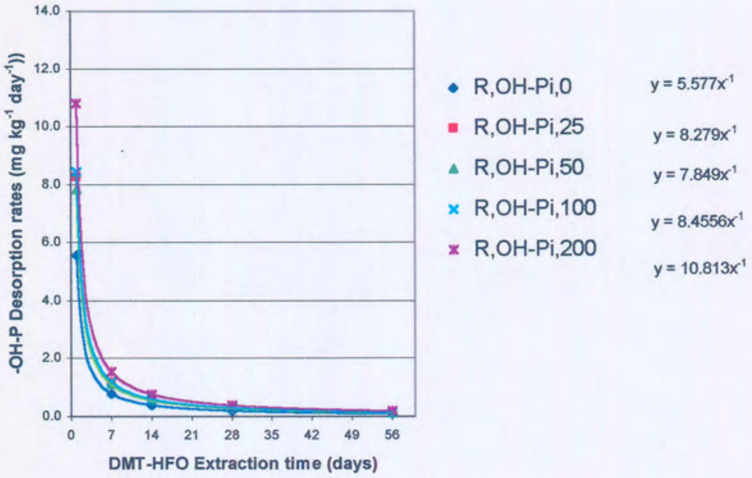

Fig. 7.2b. The effects of the added P and DMT-HFO extractions on -OH-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

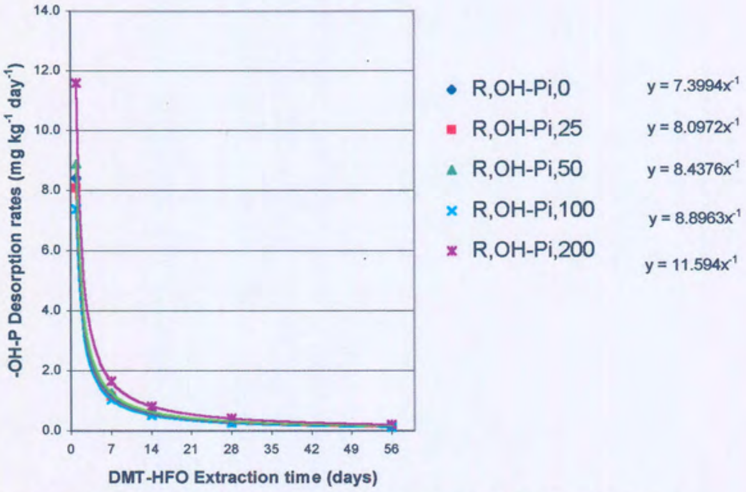

Fig. 7.2c. The effects of the added P and DMT-HFO extractions on -OH-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

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).

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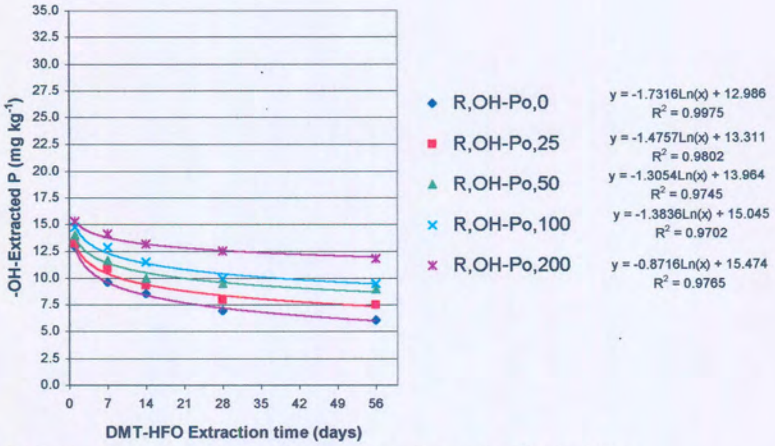

Fig. 8a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 1 day of incubation of Rustenburg soil

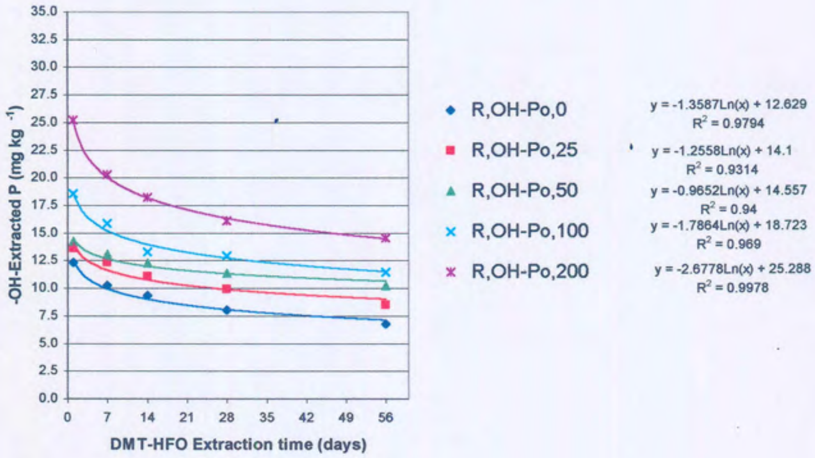

Fig. 8b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 120 days of incubation of Rustenburg soil

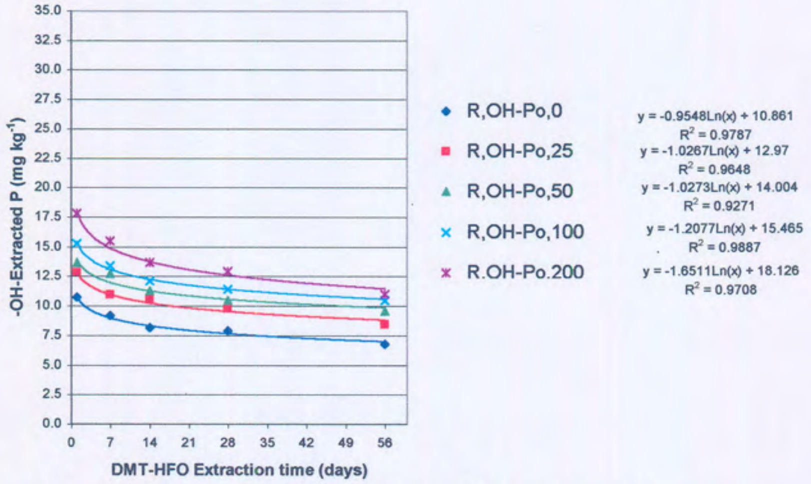

Fig. 8c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 240 days of incubation of Rustenburg soil

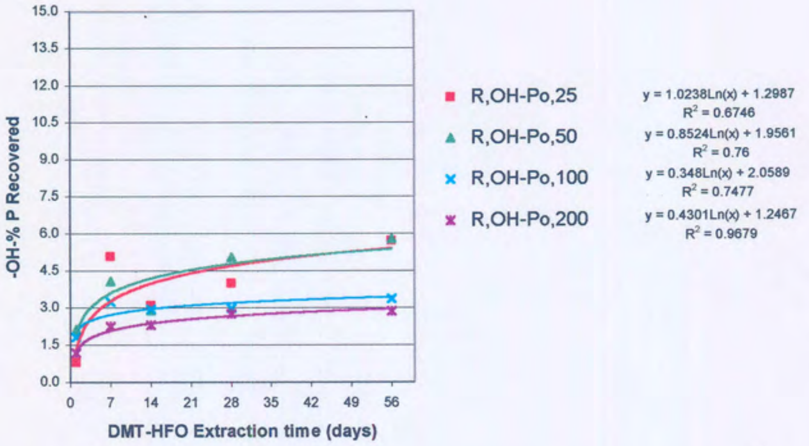

Fig. 8.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 1 day of incubation of Rustenburg soil

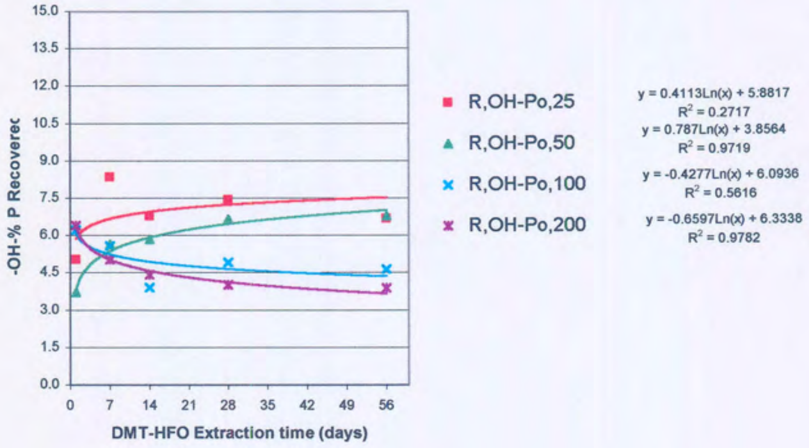

Fig. 8.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 120 days of incubation of Rustenburg soil

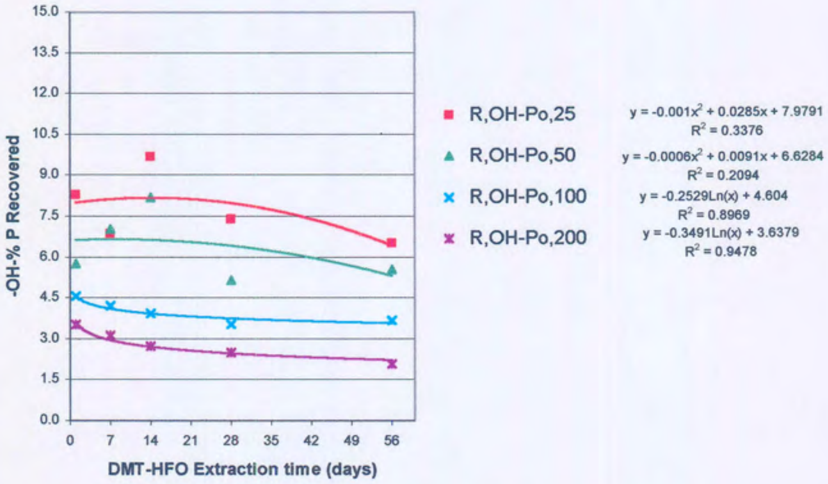

Fig. 8.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 240 days of incubation of Rustenburg soil

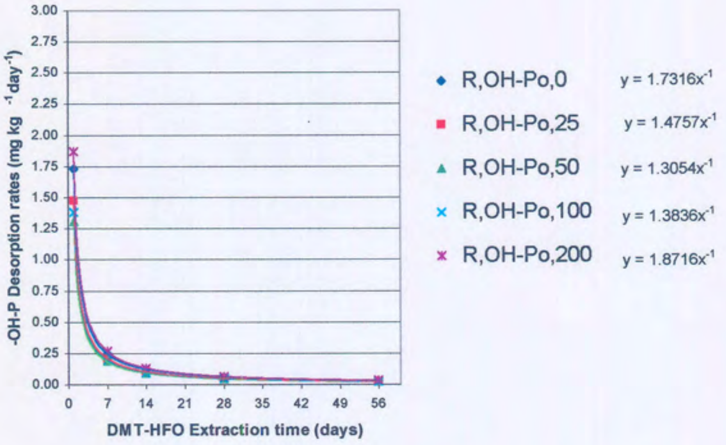

Fig. 8.2a. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

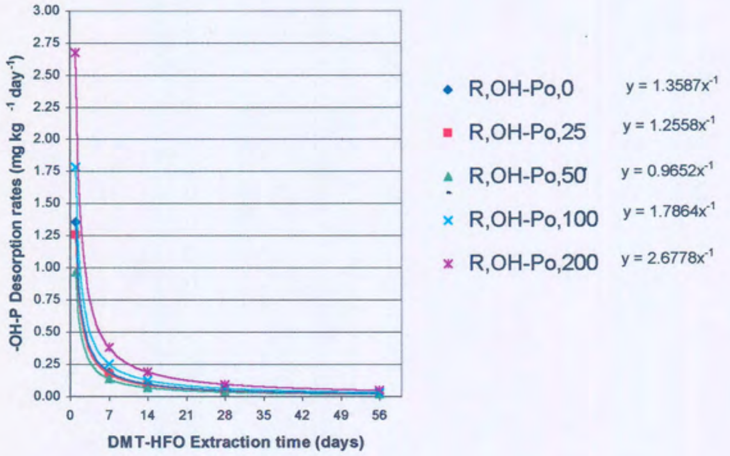

Fig. 8.2b. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

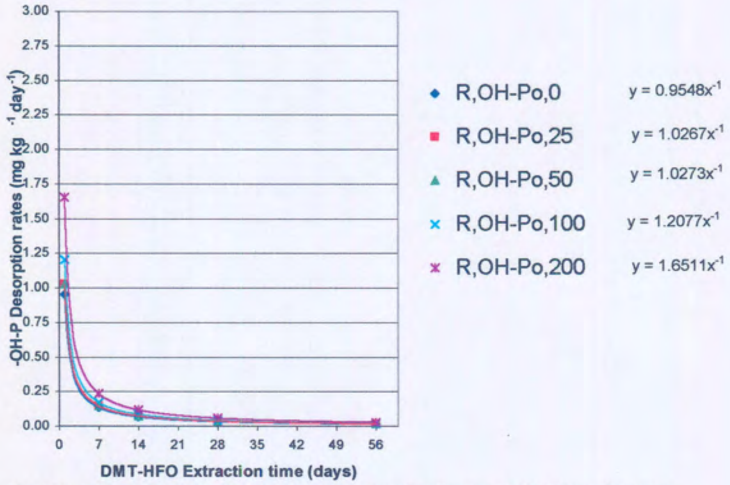

Fig. 8.2c. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

0.1M NaOH-P_0 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_0 extracts were also significant (Appendices II No. 8) with the successive DMT-HFO extractions.

However, the amounts of the –OH-P_0 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_0 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_0 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_0 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_0 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).

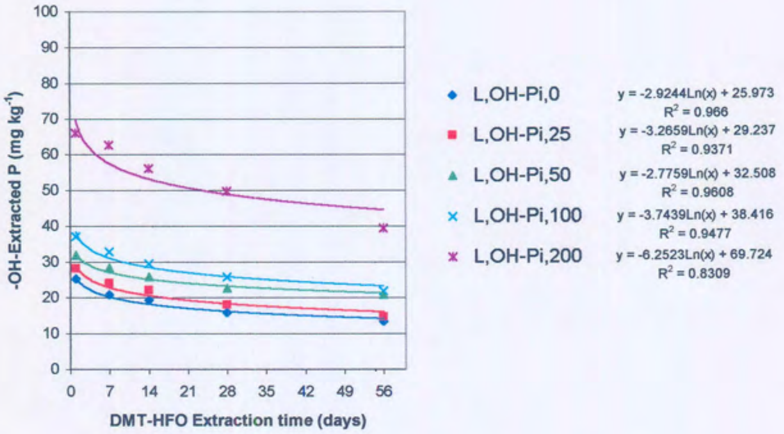

Fig. 9a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 1 day of incubation of Loskop soil

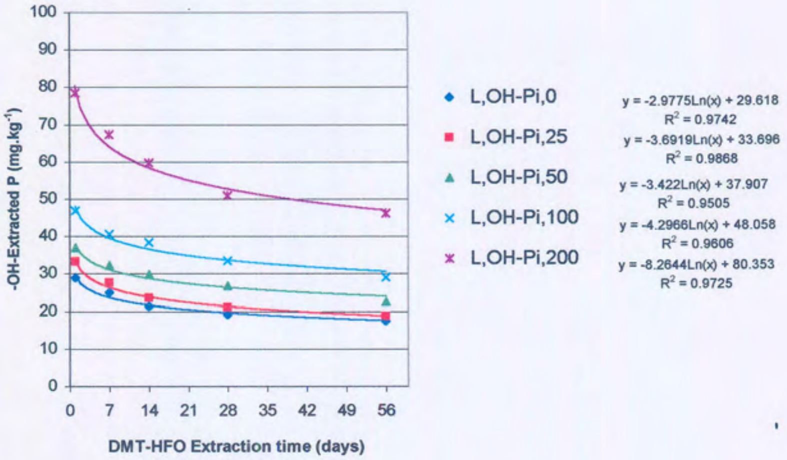

Fig. 9b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 120 days of incubation of Loskop soil

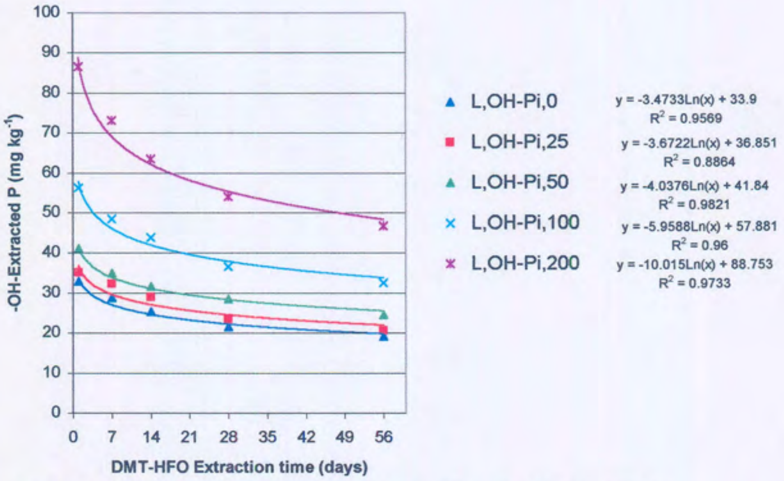

Fig. 9c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_i after 240 days of incubation of Loskop soil

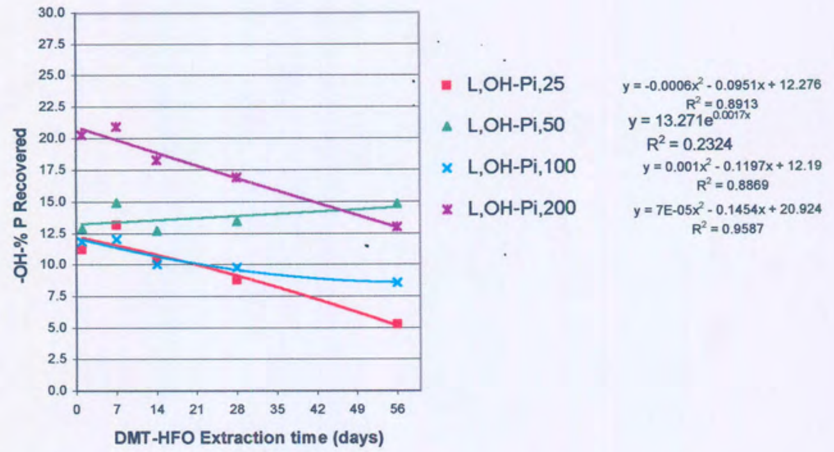

Fig. 9.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 1 day of incubation of Loskop soil

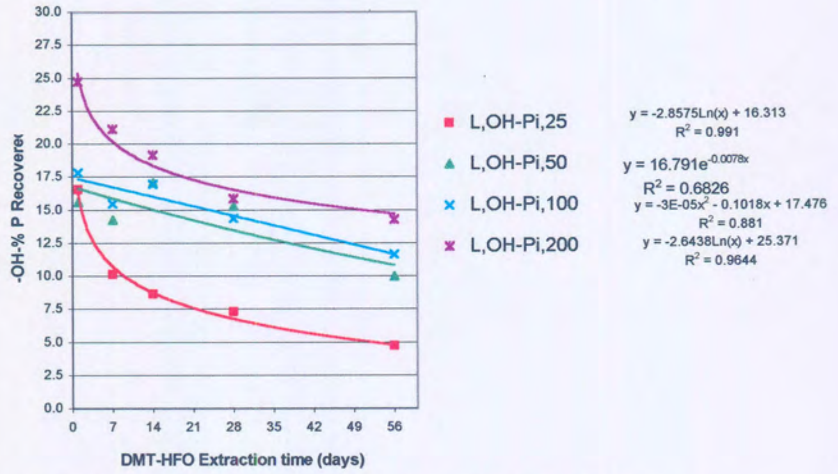

Fig. 9.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 120 days of incubation of Loskop soil

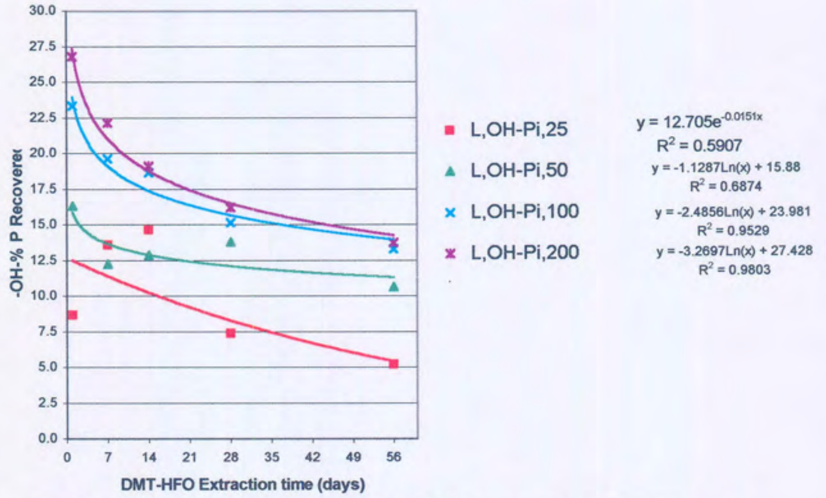

Fig. 9.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with -OH-P extractions after 240 days of incubation of Loskop soil

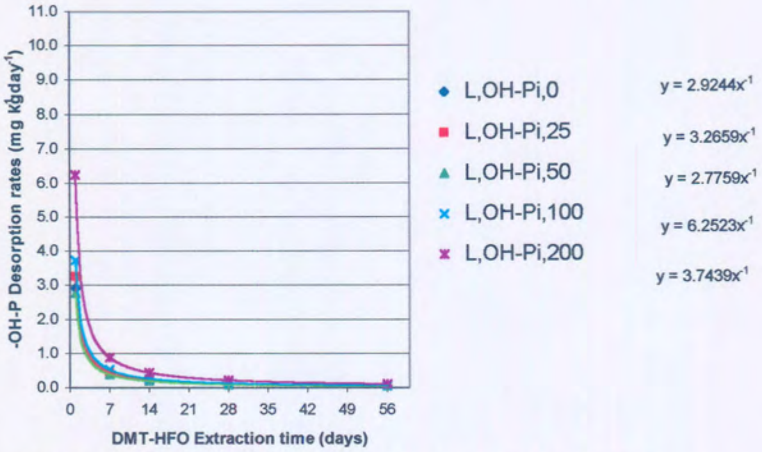

Fig. 9.2a. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

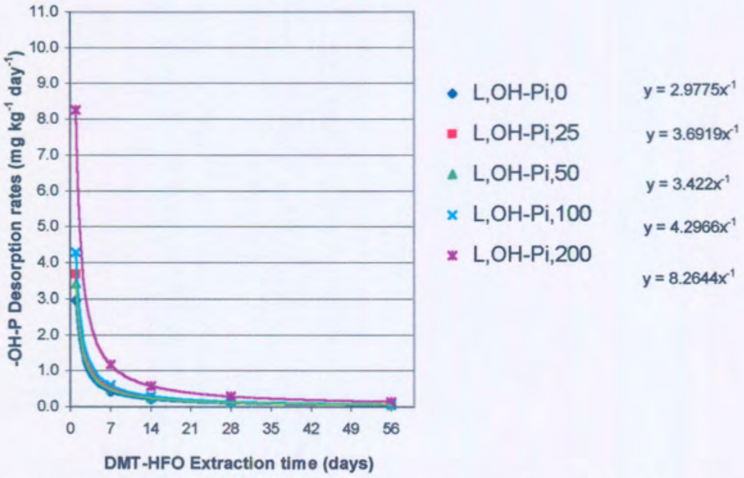

Fig. 9.2b. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

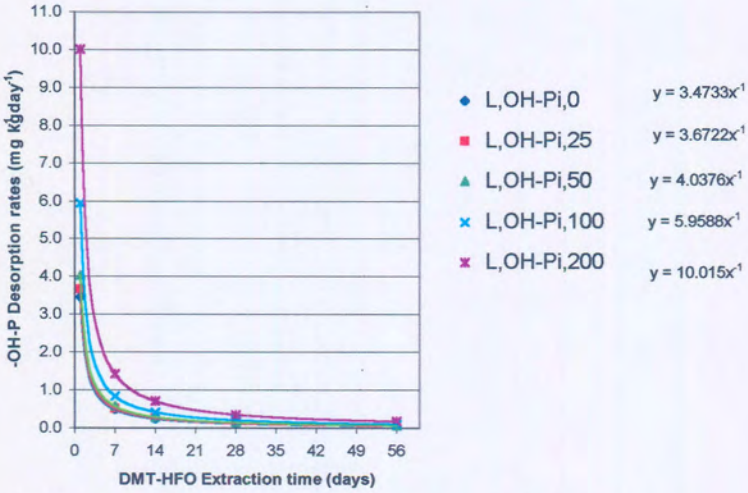

Fig. 9.2c. The effects of the added P and DMT-HFO extractions on -OH-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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$_0$ extracts:

For the Loskop soil both values for the –OH-P$_0$ 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$_0$ 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$_0$) 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$_0$ 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.

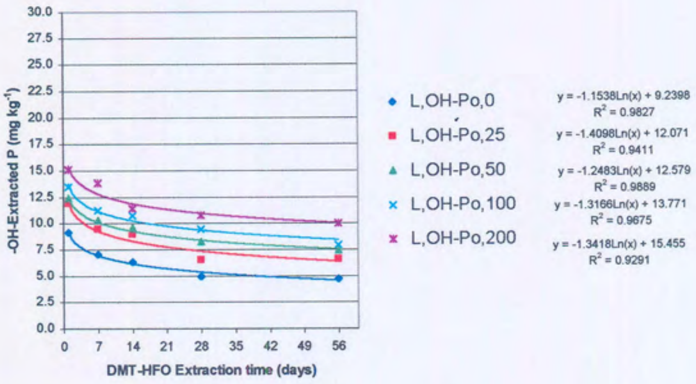

Fig. 10a. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 1 day of incubation of Loskop soil

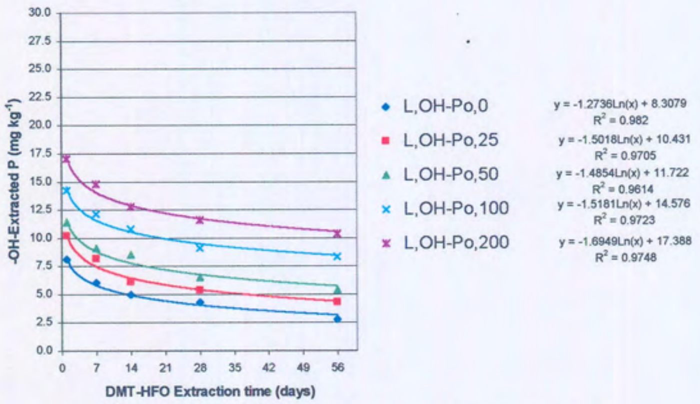

Fig. 10b. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 120 days of incubation of Loskop soil

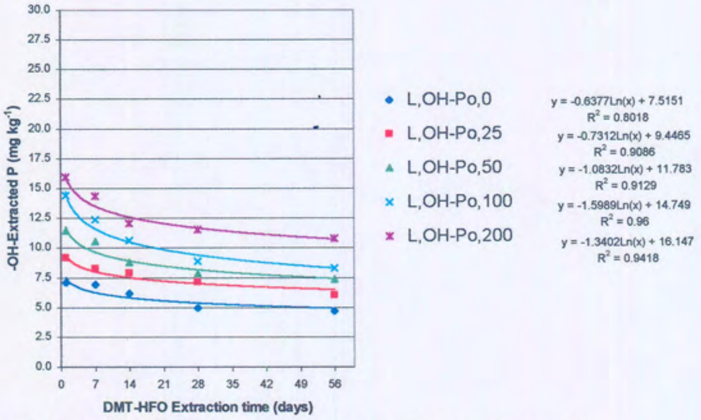

Fig. 10c. The effects of the added P and DMT-HFO extractions on the -OH-extractable P_o after 240 days of incubation of Loskop soil

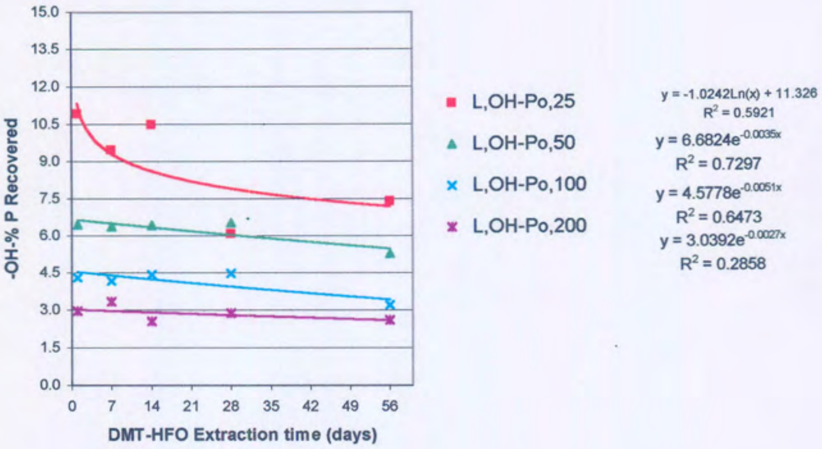

Fig.10.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 1 day of incubation of Loskop soil

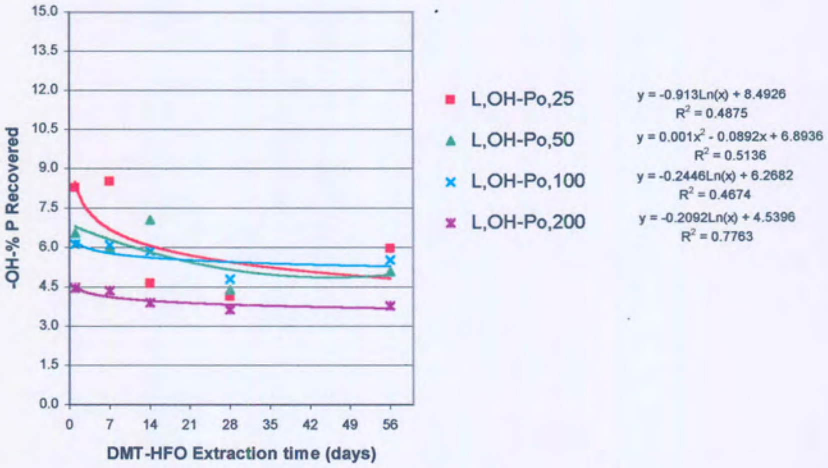

Fig.10.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 120 days of incubation of Loskop soil

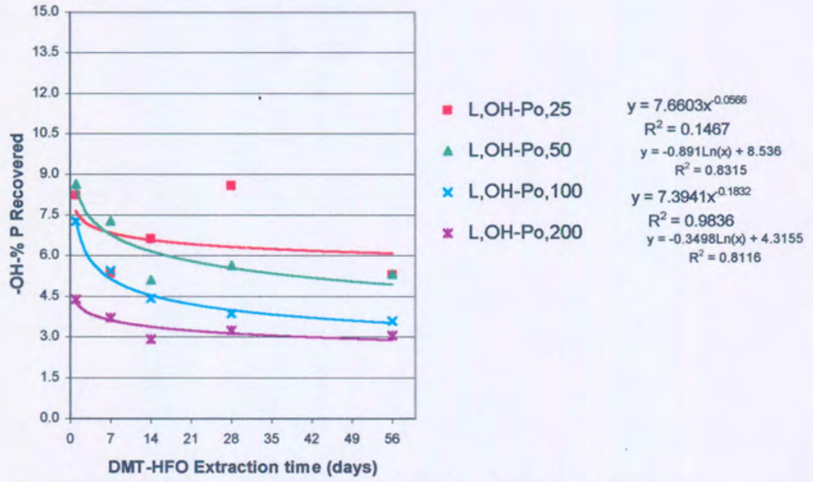

Fig.10.1c. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with -OH-P extractions after 240 days of incubation of Loskop soil

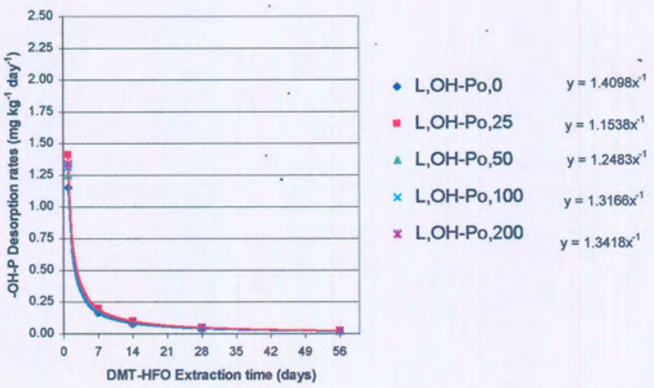

Fig. 10.2a. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

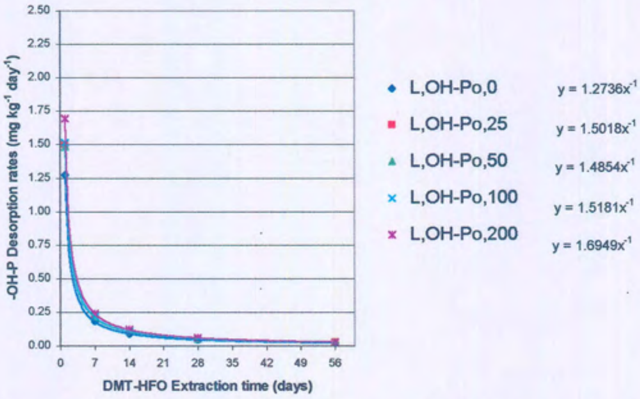

Fig. 10.2b. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

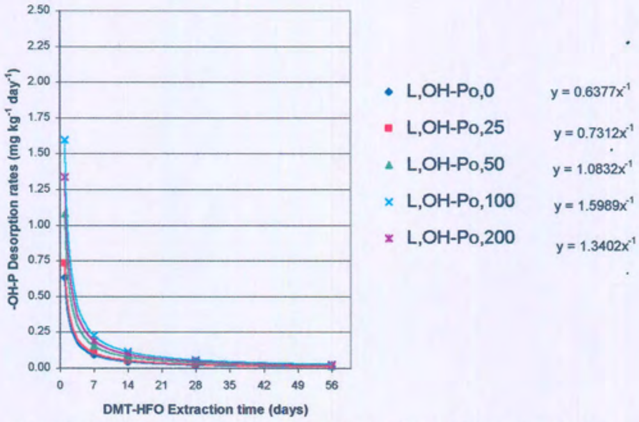

Fig. 10.2c. The effects of the added P and DMT-HFO extractions on -OH-P$_o$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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).

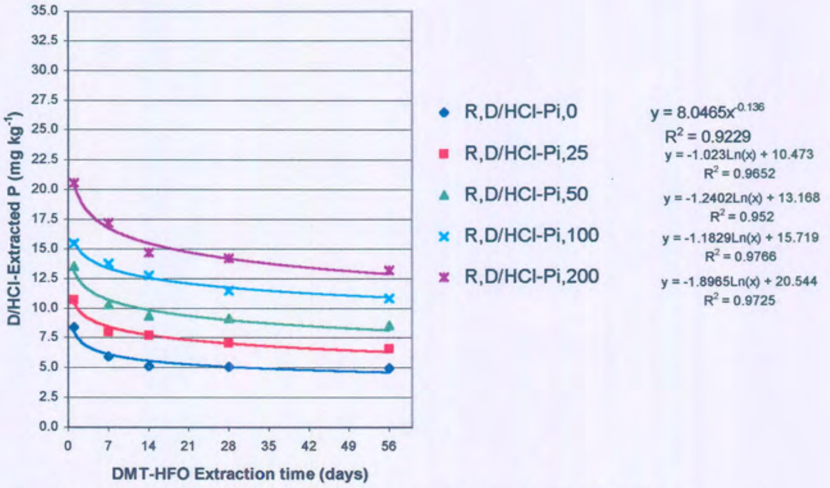

Fig. 11a. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 1 day of incubations of Rustenburg soil

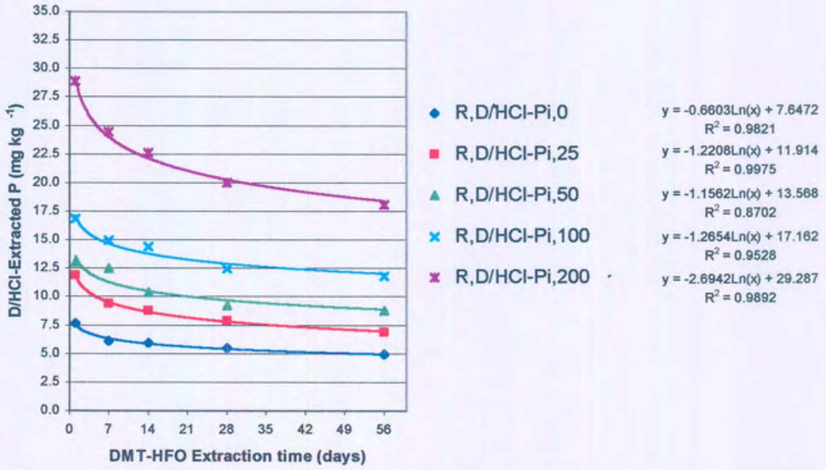

Fig. 11b. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 120 days of incubations of Rustenburg soil

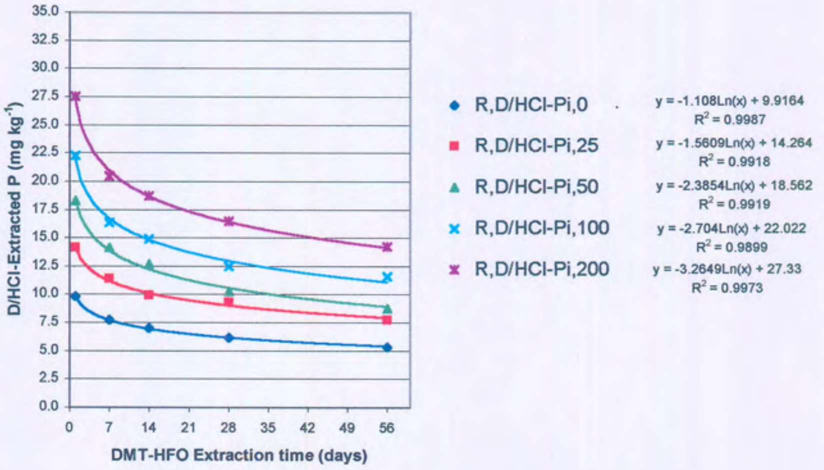

Fig. 11c. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P_i after 240 days of incubation of Rustenburg soil

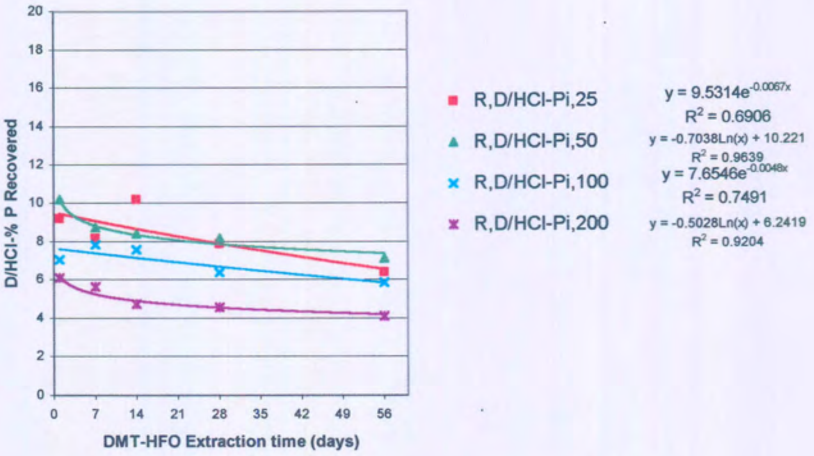

Fig. 11.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 1 day of incubation of Rustenburg soil

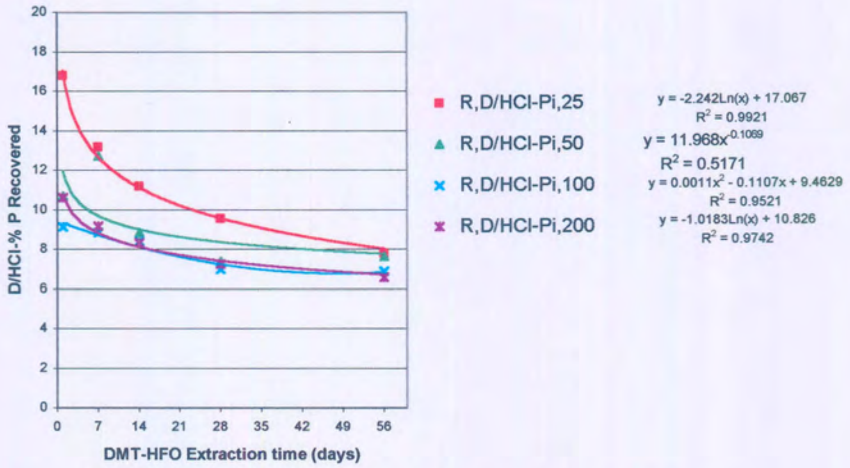

Fig. 11.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 120 days of incubation of Rustenburg soil

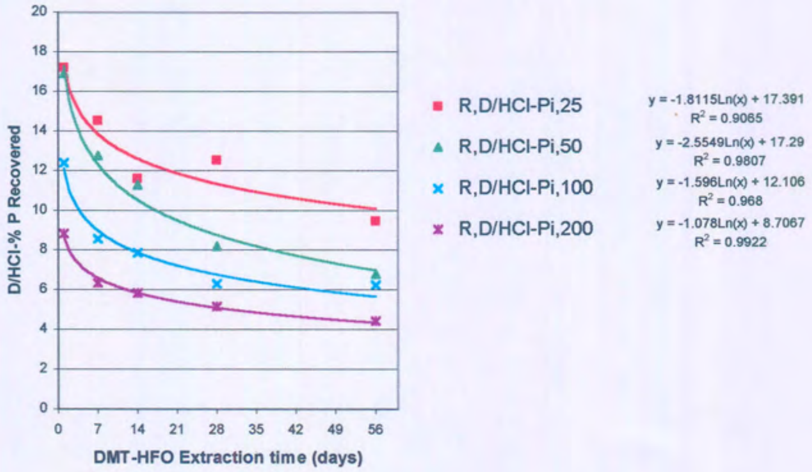

Fig. 11.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 240 days of incubation of Rustenburg soil

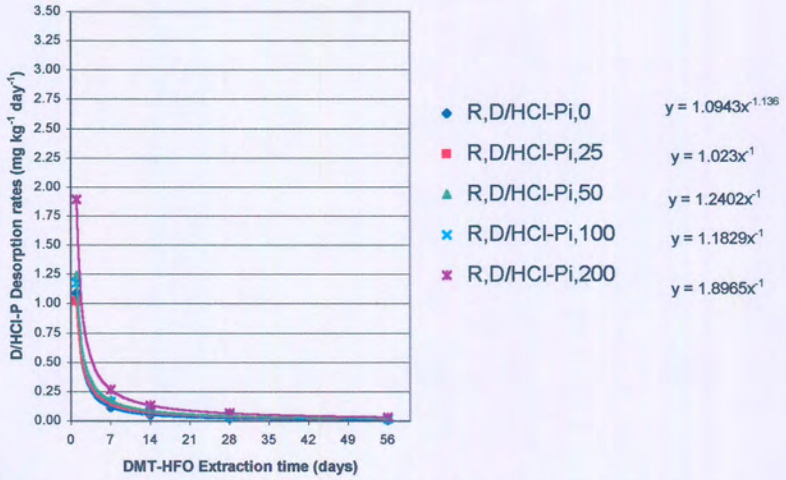

Fig. 11.2a. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

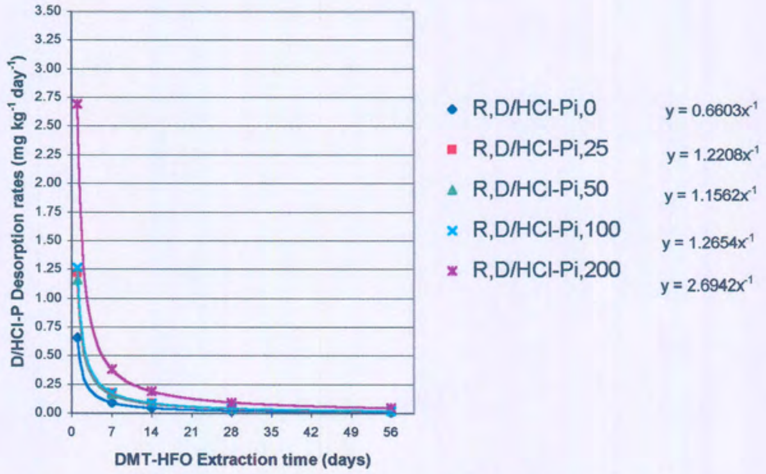

Fig. 11.2b. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubations of Rustenburg soil

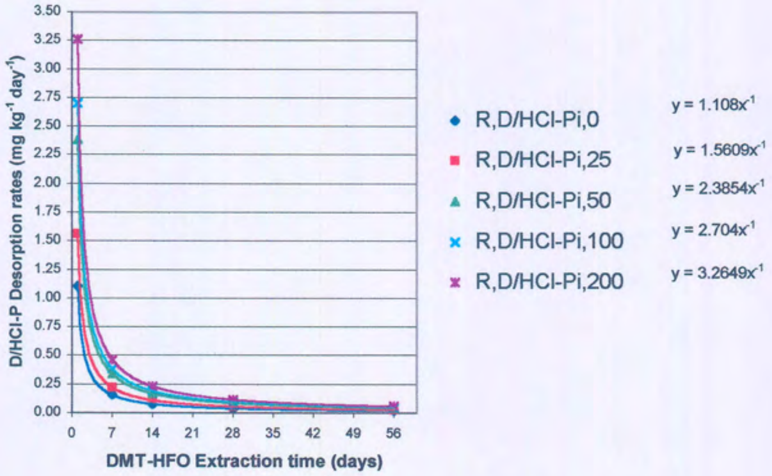

Fig. 11.2c. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

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

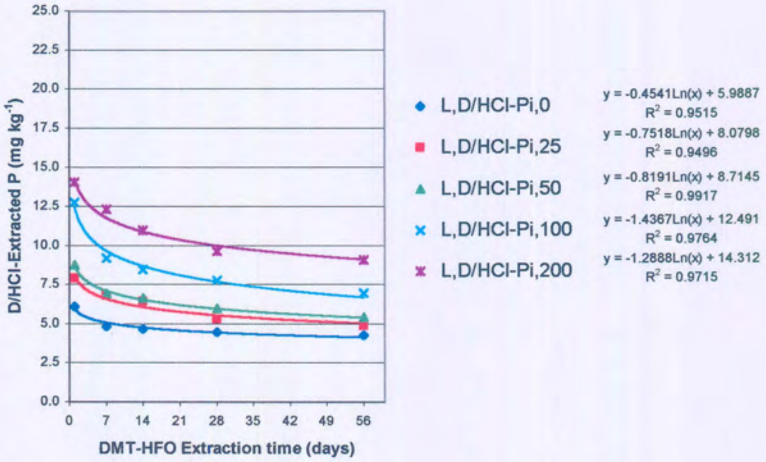

Fig. 12a. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P$_i$ after 1 day of incubation of Loskop soil

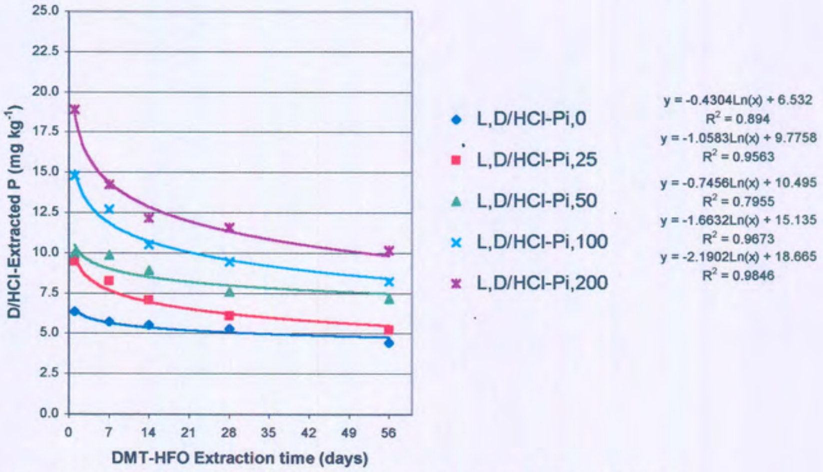

Fig. 12b. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P$_i$ after 120 days of incubation of Loskop soil

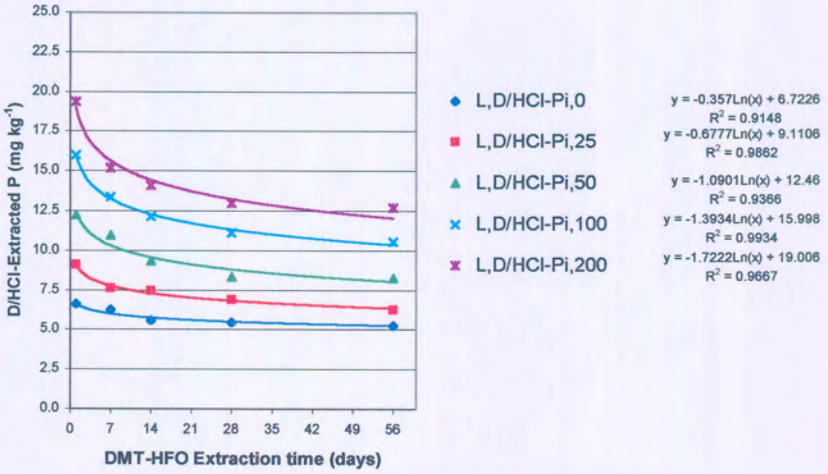

Fig. 12c. The effects of the added P and DMT-HFO extractions on the D/HCl-extractable P$_i$ after 240 days of incubation of Loskop soil

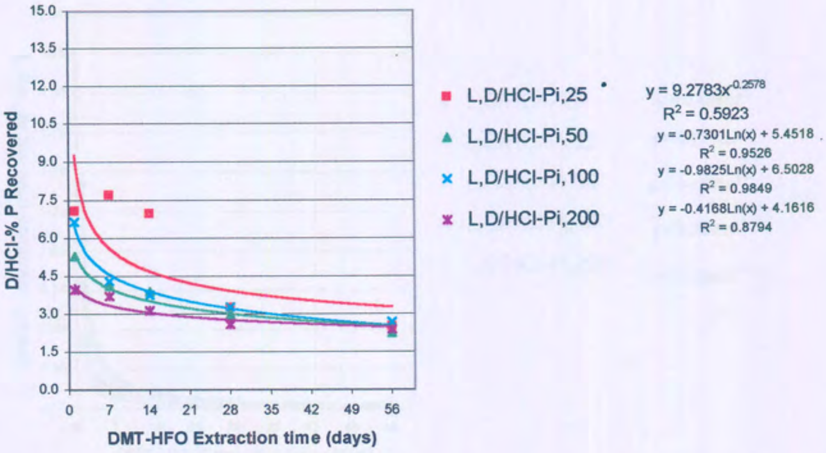

Fig. 12.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 1 day of incubation of Loskop soil

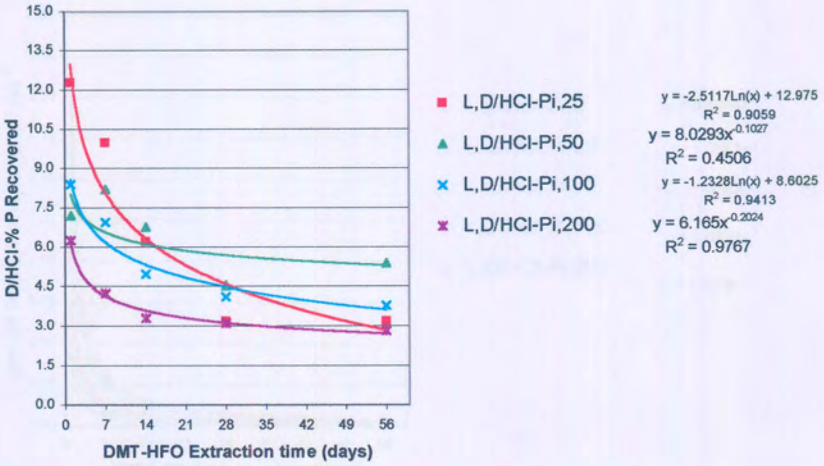

Fig. 12.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 120 days of incubation of Loskop soil

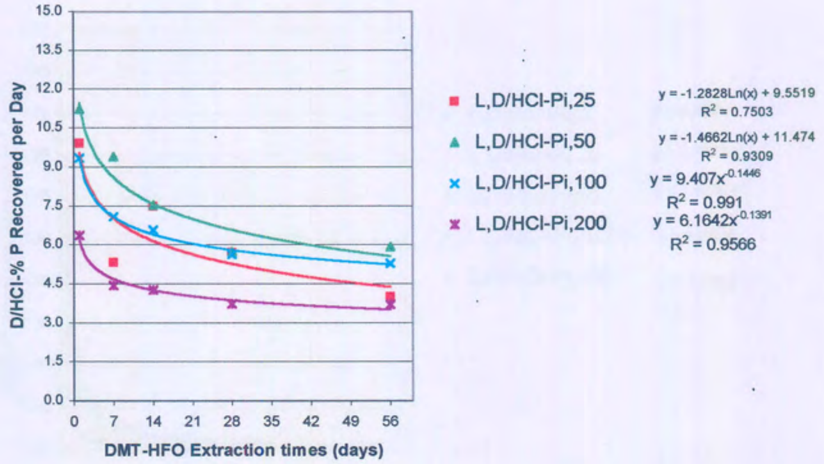

Fig. 12.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with D/HCl-P extractions after 240 days of incubation of Loskop soil

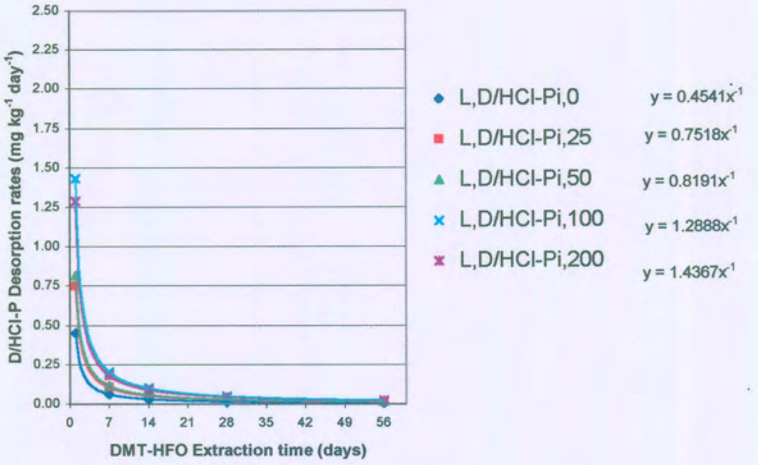

Fig. 12.2a. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

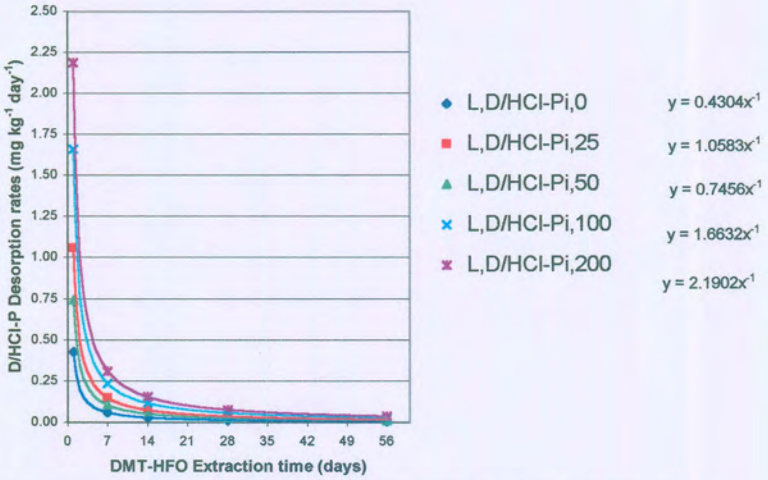

Fig. 12.2b. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

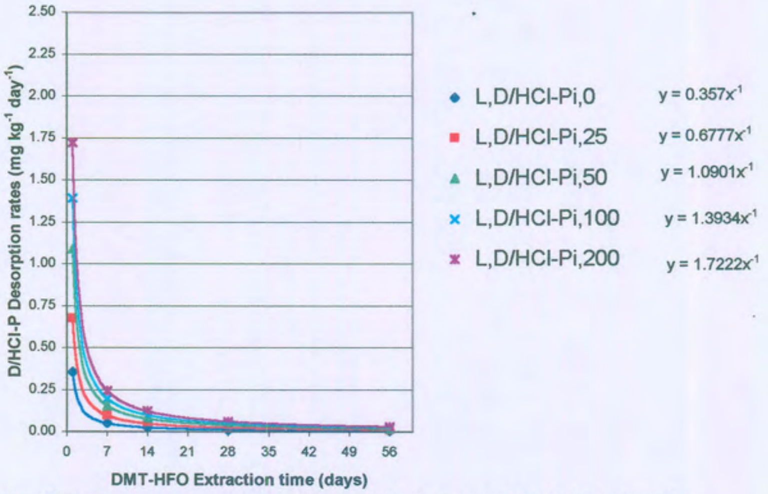

Fig. 12.2c. The effects of the added P and DMT-HFO extractions on D/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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).

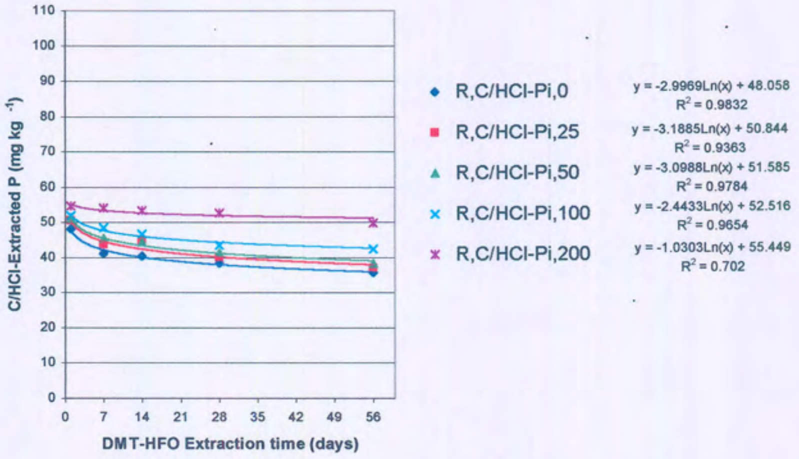

Fig. 13a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 1 day of incubation of Rustenburg soil

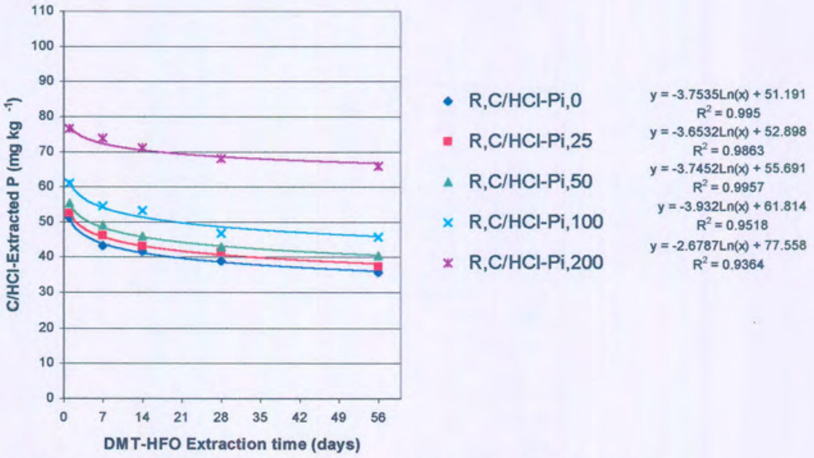

Fig. 13b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 120 days of incubation of Rustenburg soil

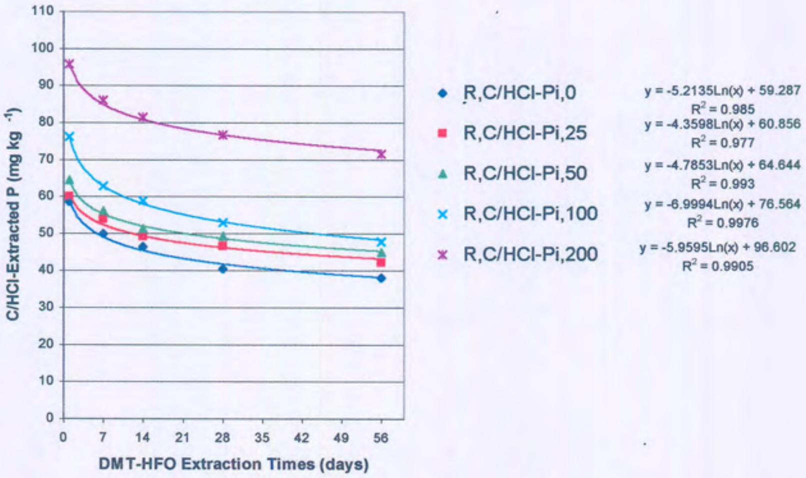

Fig. 13c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 240 days of incubation of Rustenburg soil

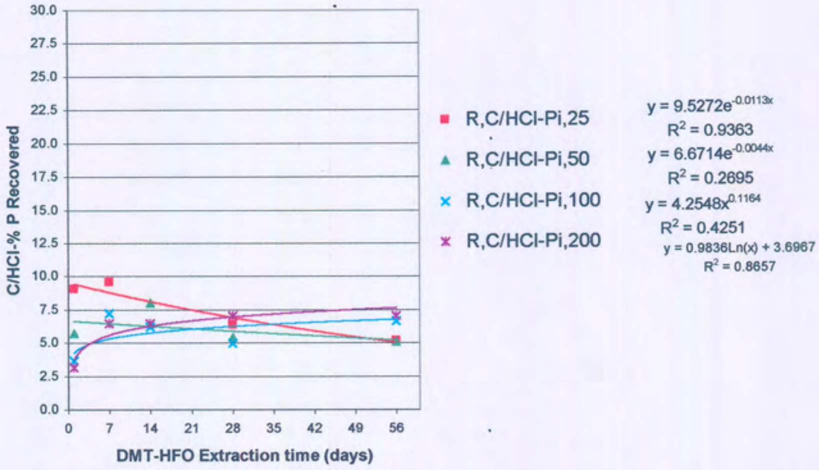

Fig. 13.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 1 day of incubation of Rustenburg soil

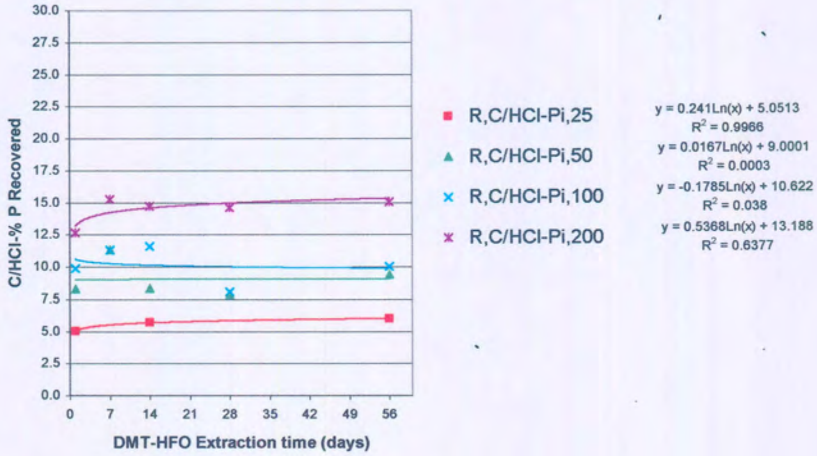

Fig. 13.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 120 days of incubation of Rustenburg soil

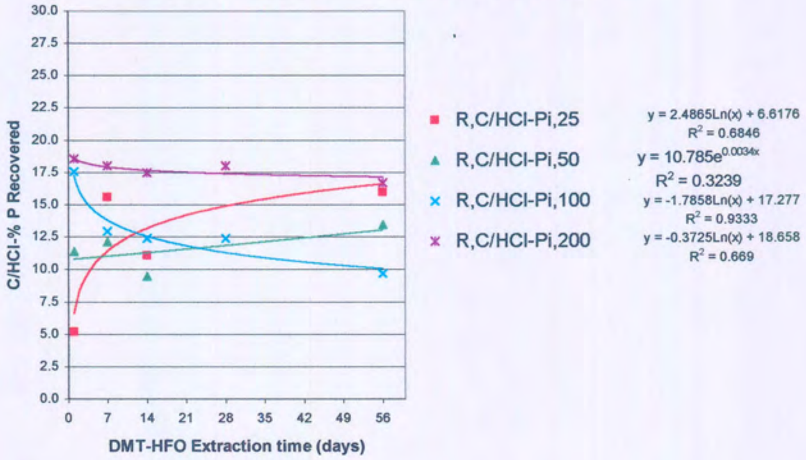

Fig. 13.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 240 days of incubation of Rustenburg soil

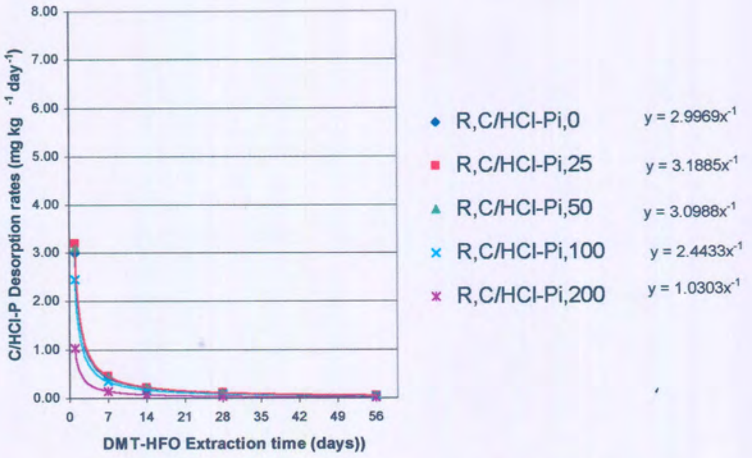

Fig. 13.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Rustenburg soil

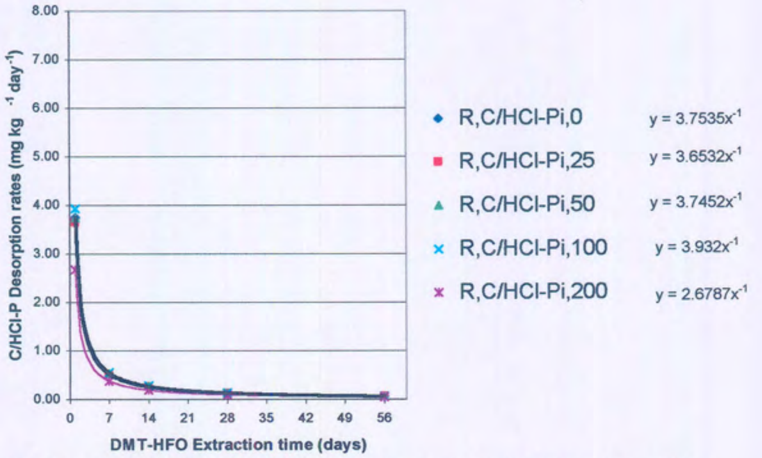

Fig. 13.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

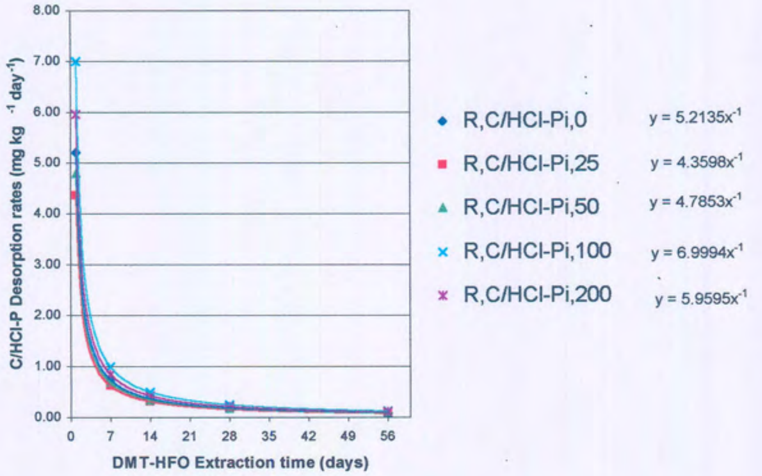

Fig. 13.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_i desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

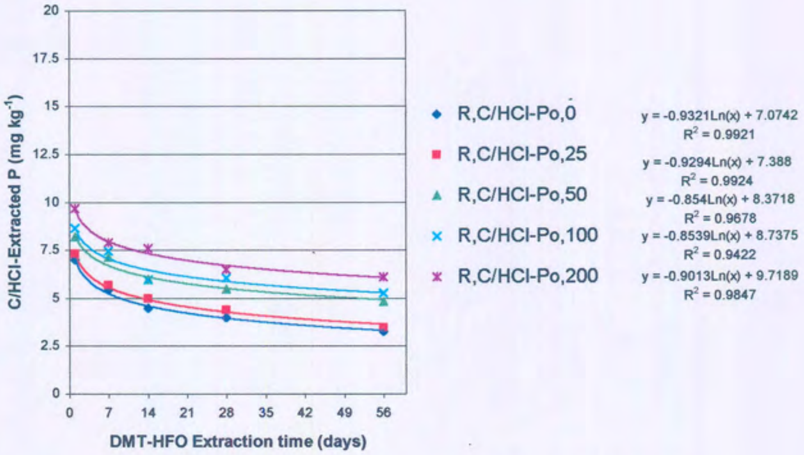

Fig. 14a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 1 day days of incubation of Rustenburg soil

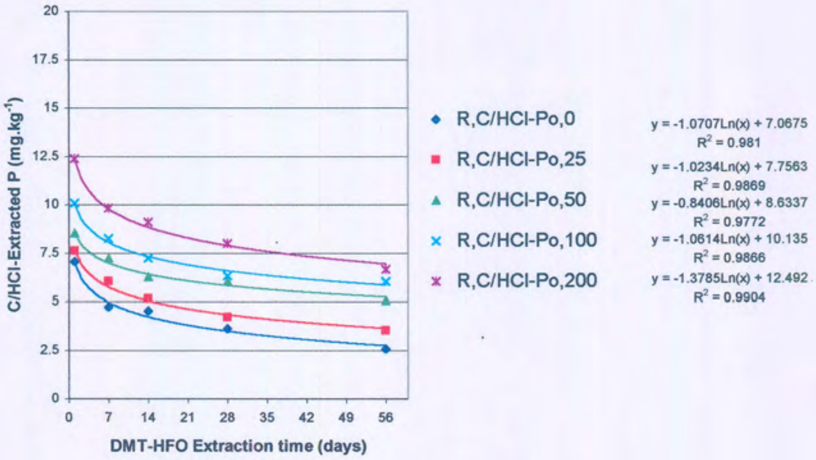

Fig. 14b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 120 days of incubation of Rustenburg soil

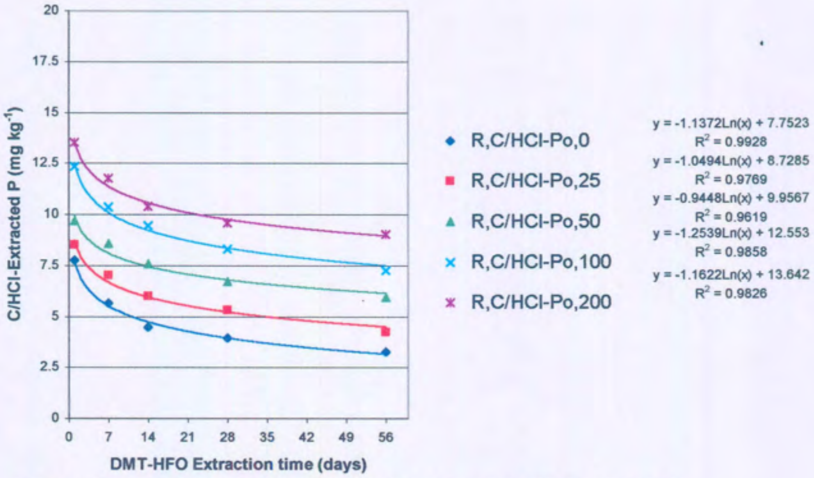

Fig. 14c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 240 days of incubation of Rustenburg soil

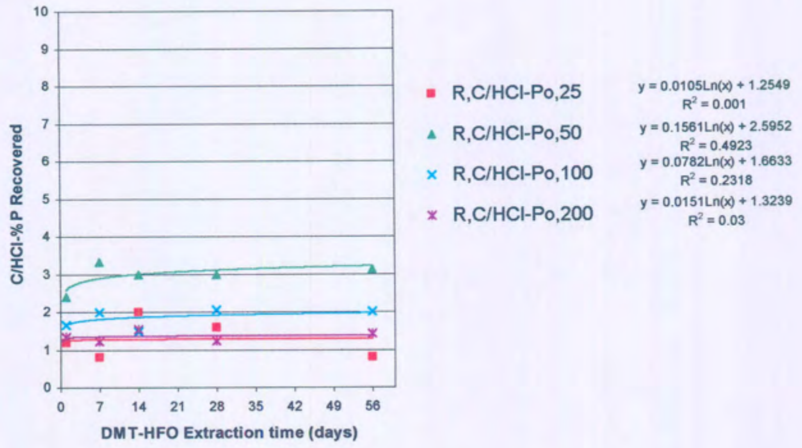

Fig. 14.1a.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 1 day of incubation of Rustenburg soil

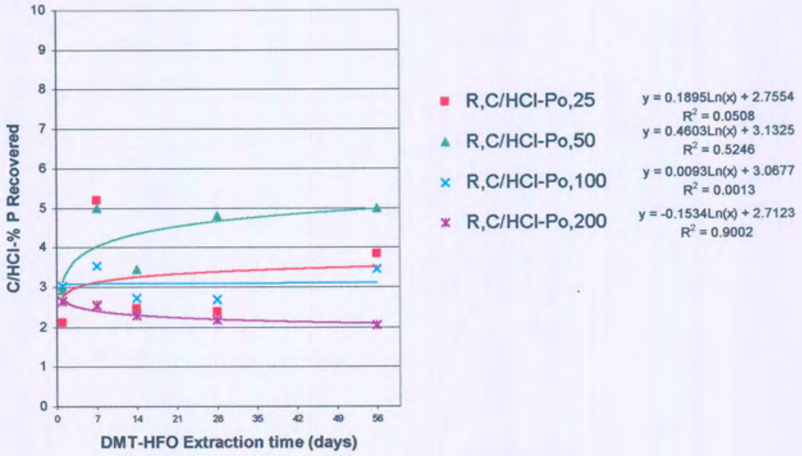

Fig. 14.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 120 days of incubation of Rustenburg soil

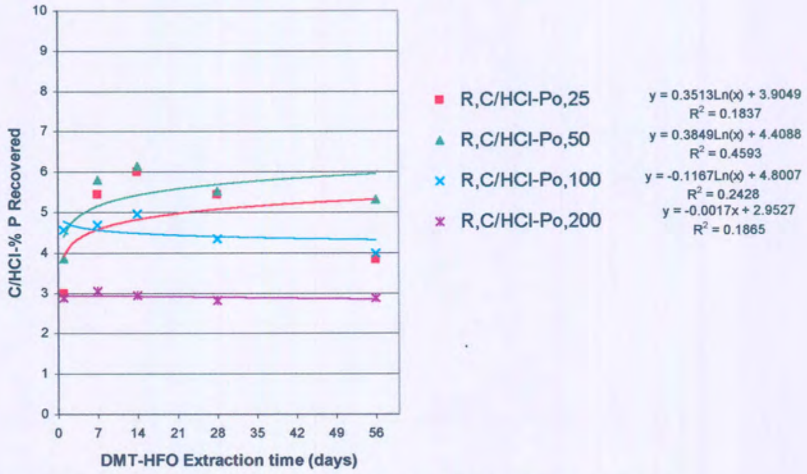

Fig. 14.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 240 days of incubation of Rustenburg soil

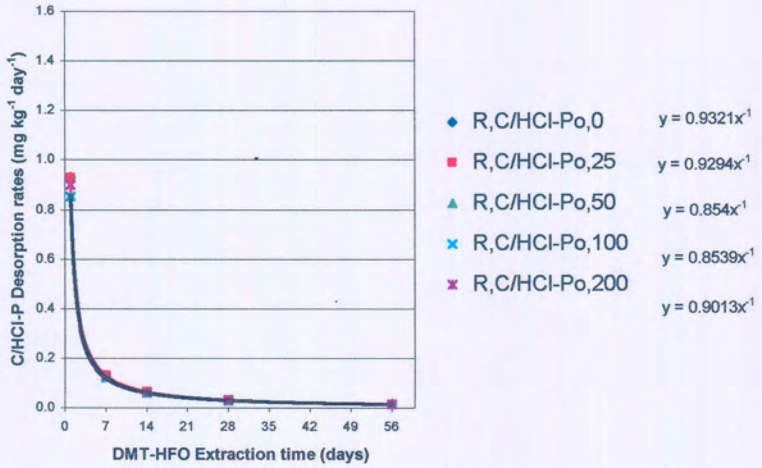

Fig. 14.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubations of Rustenburg soil

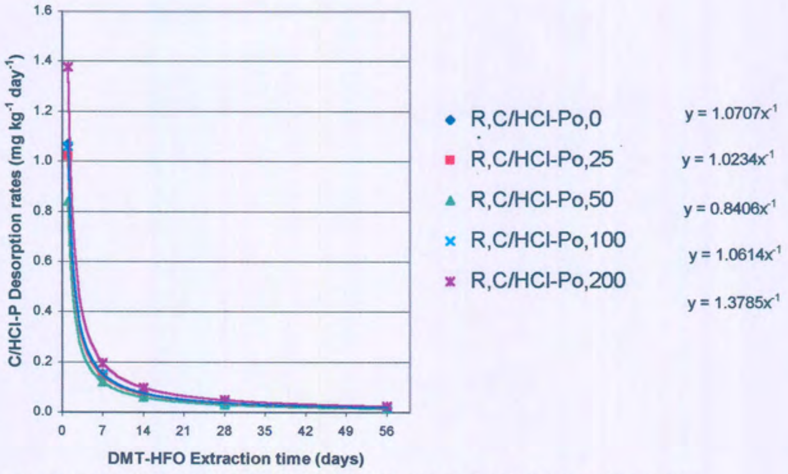

Fig. 14.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Rustenburg soil

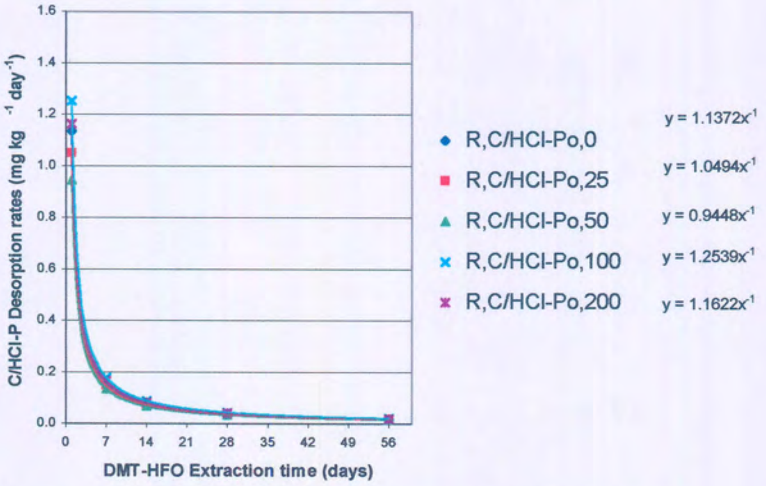

Fig. 14.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Rustenburg soil

C/HCl-P_0 extracts

The conc. HCl-P_0 extracts (C/HCl-P_0) 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_0 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.

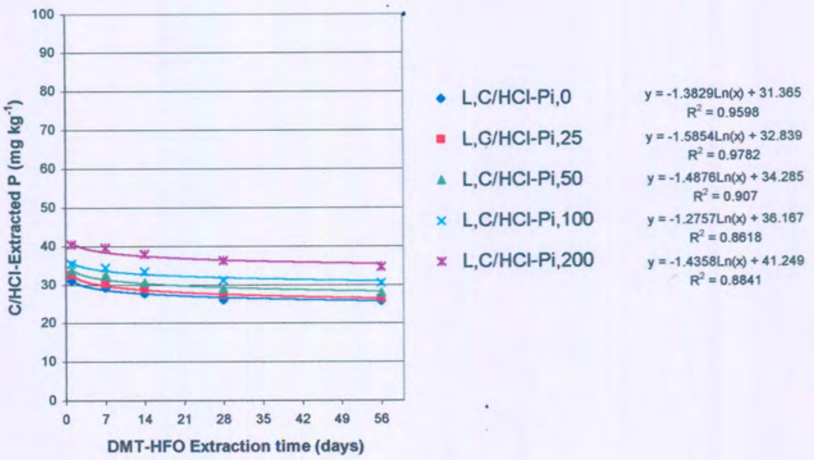

Fig. 15a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 1 day of incubation of Loskop soil

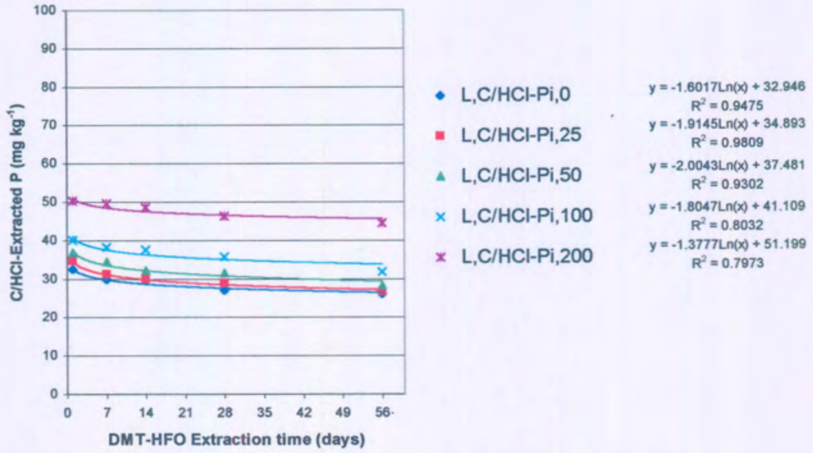

Fig. 15b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 120 days of incubation of Loskop soil

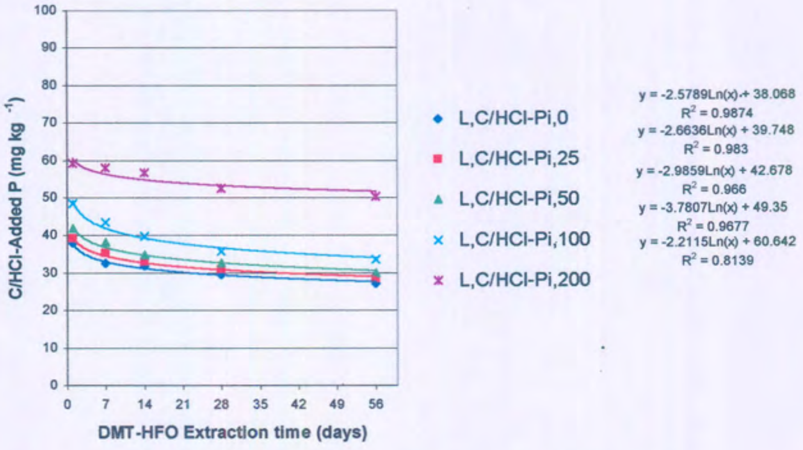

Fig. 15c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_i after 240 days of incubation of Loskop soil

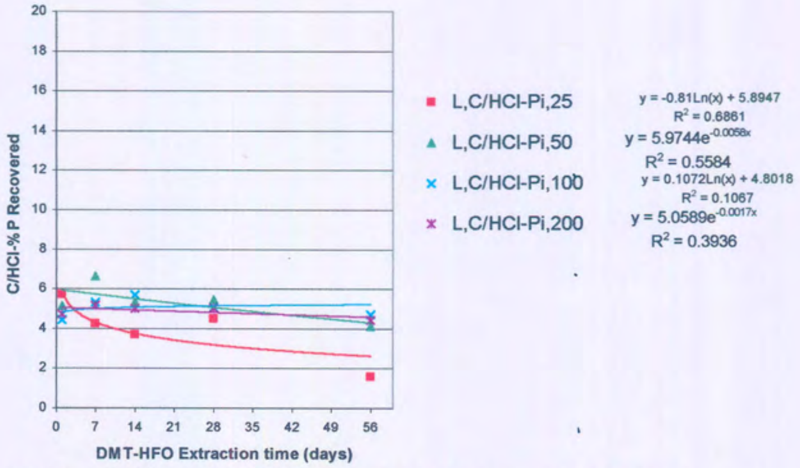

Fig. 15.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 1 day of incubation of Loskop soil

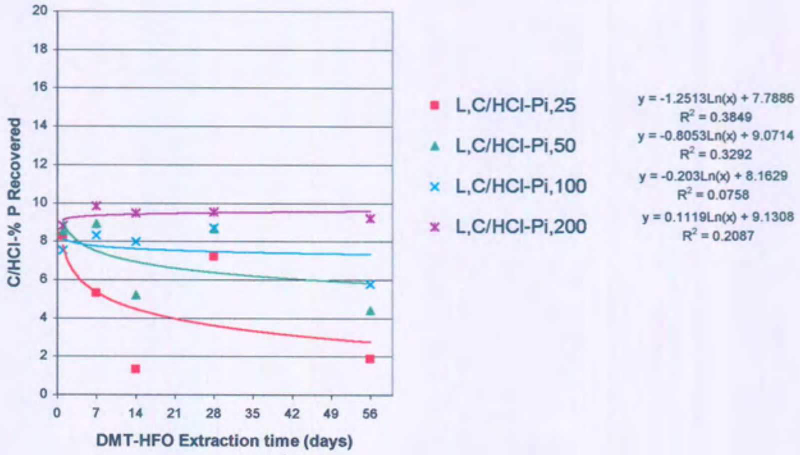

Fig. 15.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 120 days of incubation of Loskop soil

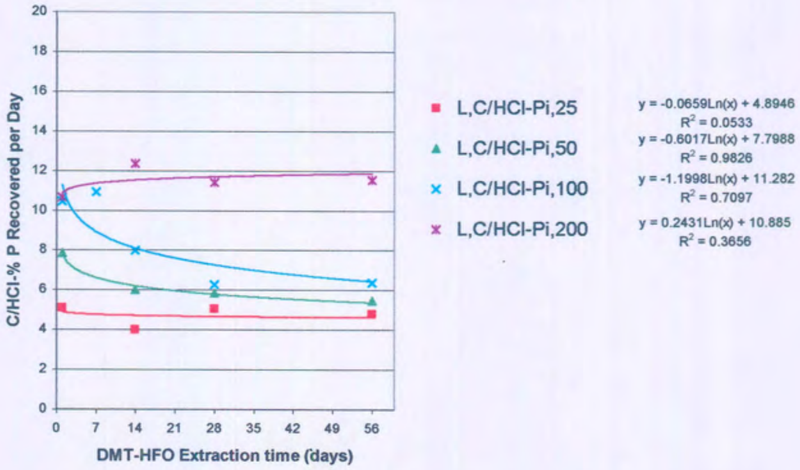

Fig. 15.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with C/HCl-P extractions after 240 days of incubation of Loskop soil

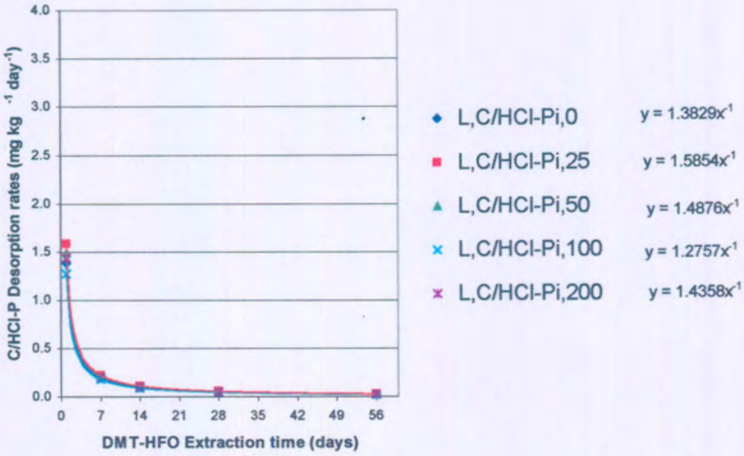

Fig. 15.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

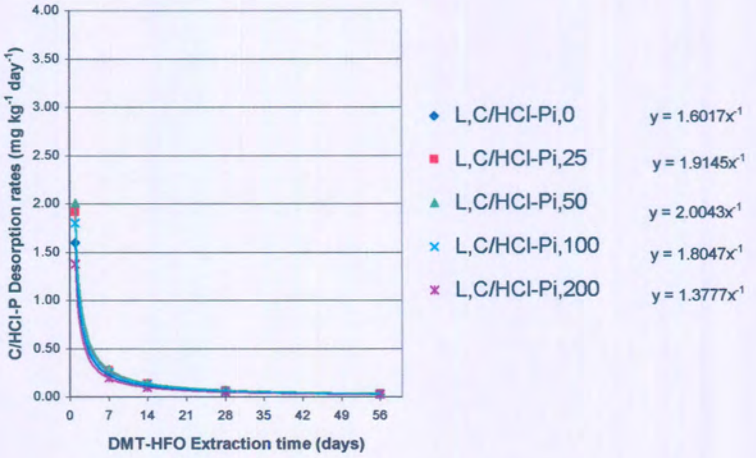

Fig. 15.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

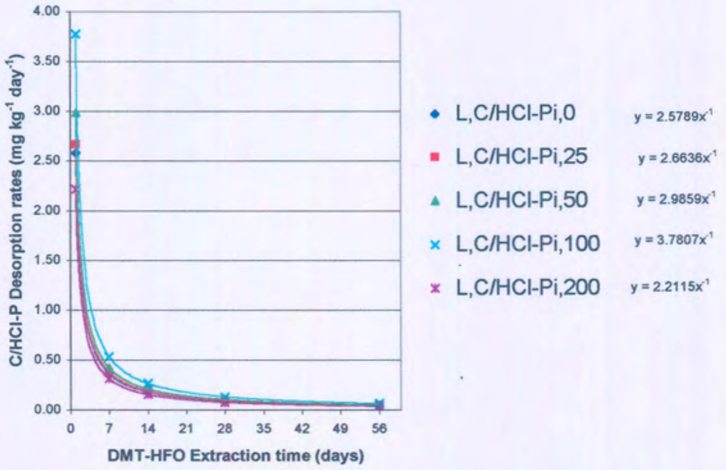

Fig. 15.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P$_i$ desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

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.,

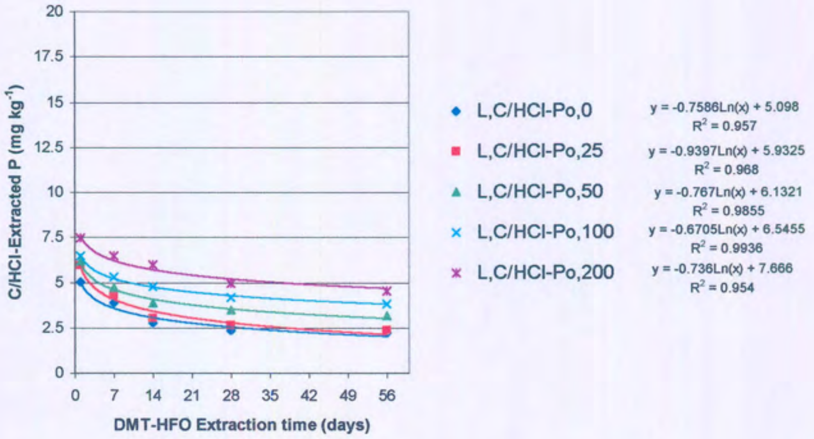

Fig. 16a. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 1 day of incubation of Loskop soil

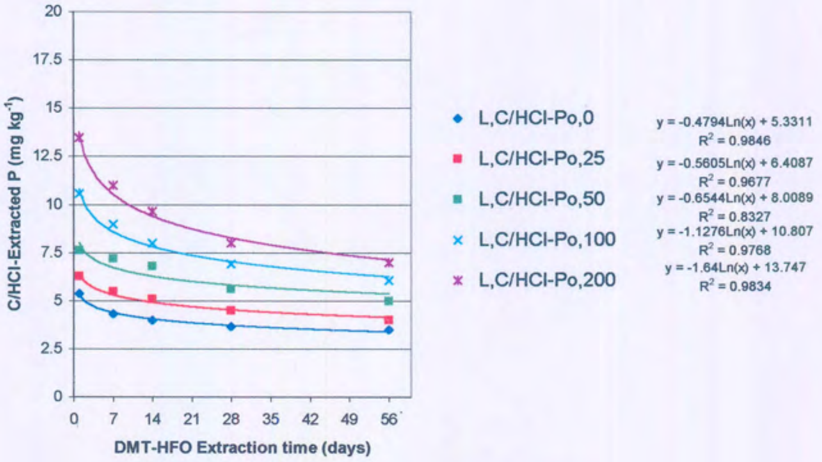

Fig. 16b. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 120 days of incubation of Loskop soil

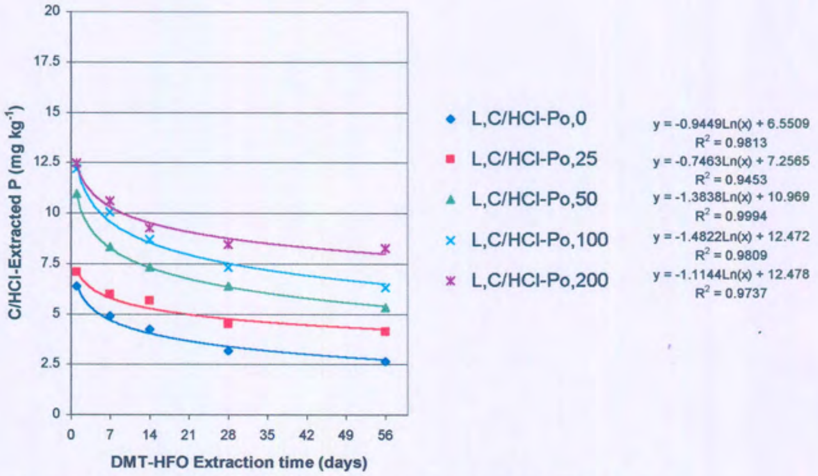

Fig. 16c. The effects of the added P and DMT-HFO extractions on the C/HCl-extractable P_o after 240 days of incubation of Loskop soil

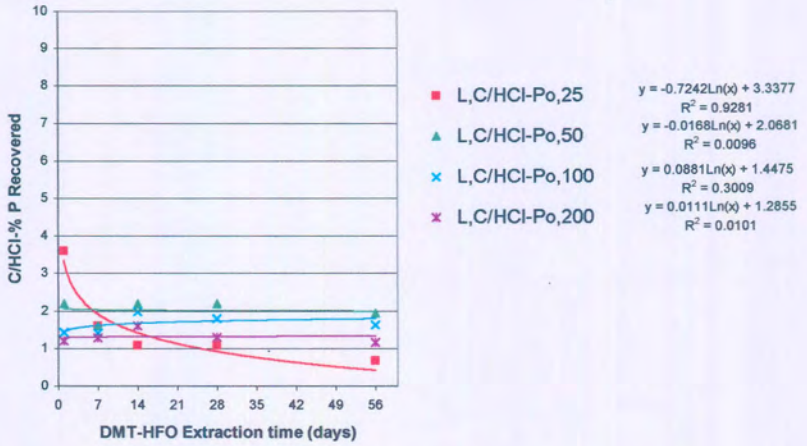

Fig. 16.1a. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 1 day of incubation of Loskop soil

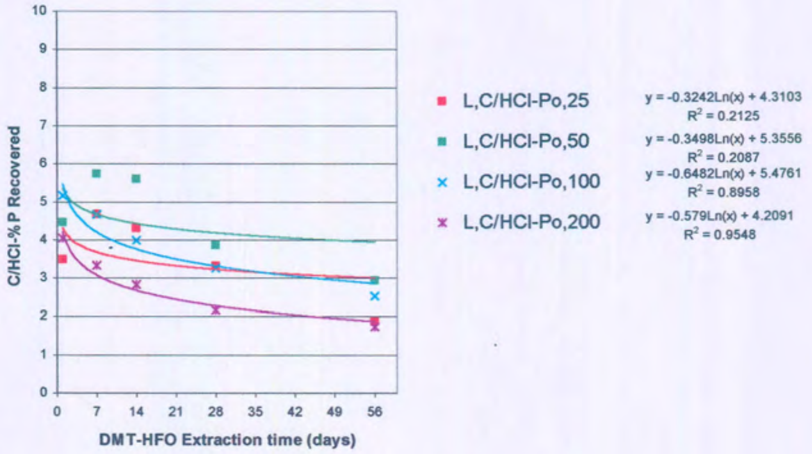

Fig. 16.1b. The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 120 days of incubation of Loskop soil

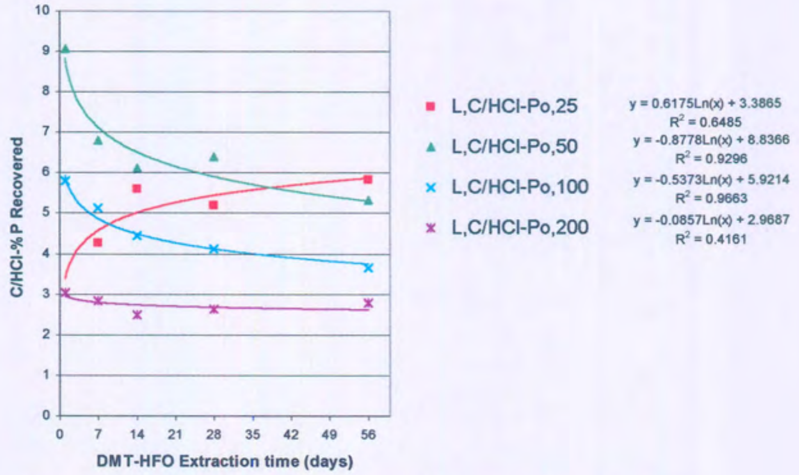

Fig.16.1c.The effects of the added P and DMT-HFO extractions on percentage P_o recovered with C/HCl-P extractions after 240 days of incubation of Loskop soil

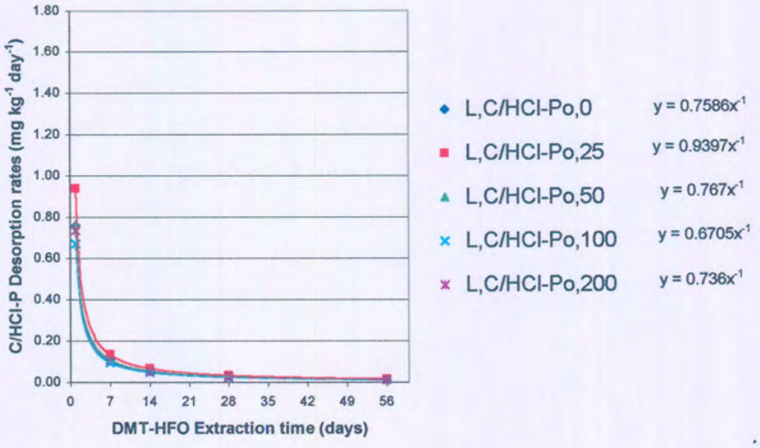

Fig. 16.2a. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

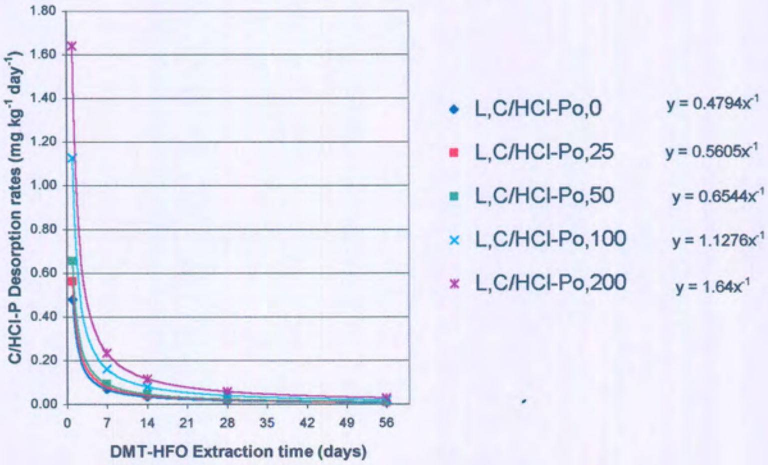

Fig. 16.2b. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

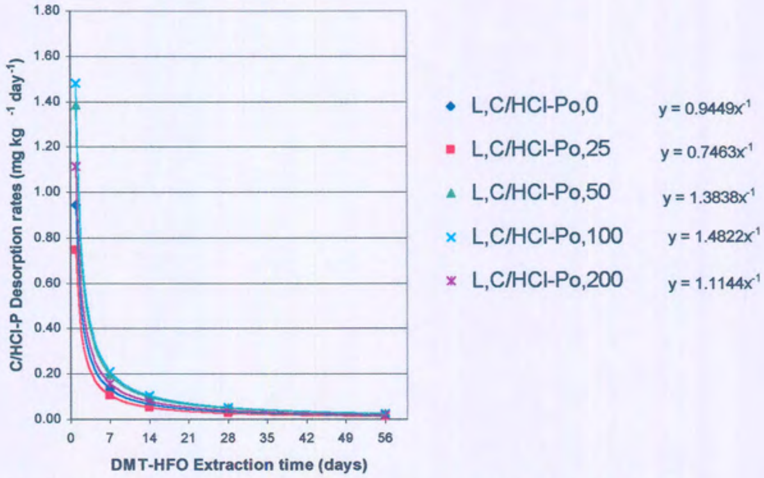

Fig.16.2c. The effects of the added P and DMT-HFO extractions on C/HCl-P_o desorption rates (mg kg^{-1} day^{-1}) after 240 days of incubation of Loskop soil

(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

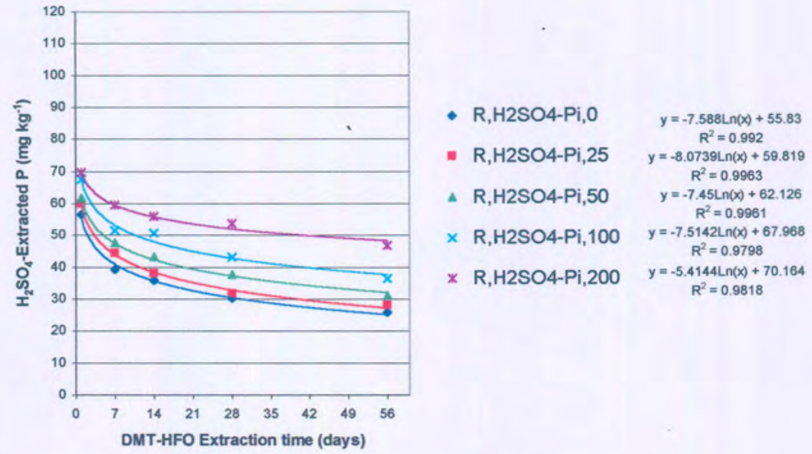

Fig. 17a. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 1 day of incubation of Rustenburg soil

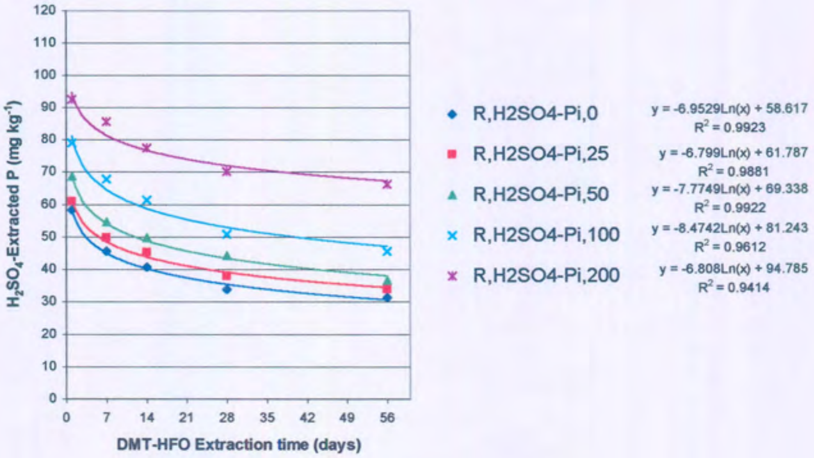

Fig. 17b. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 120 days of incubation of Rustenburg soil

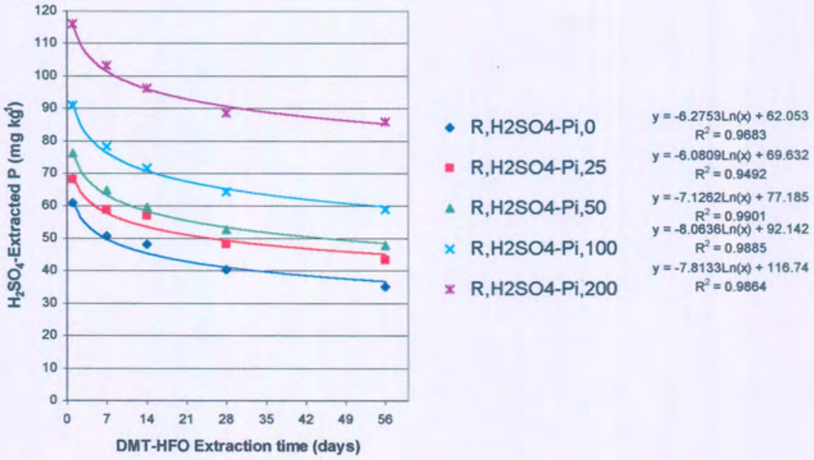

Fig. 17c. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 240 days of incubation of Rustenburg soil

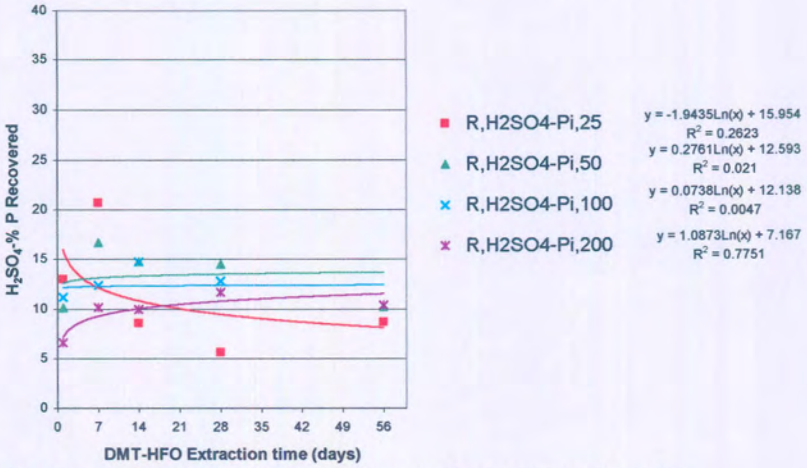

Fig. 17.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 1 day of incubation of Rustenburg soil

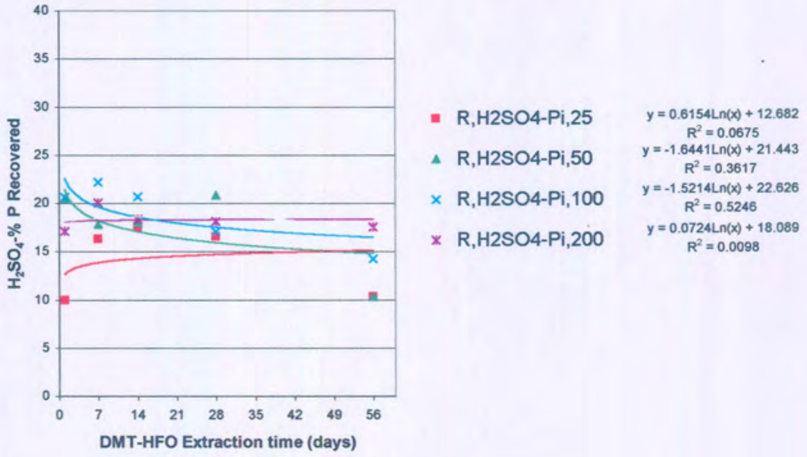

Fig. 17.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 120 days of incubation of Rustenburg soil

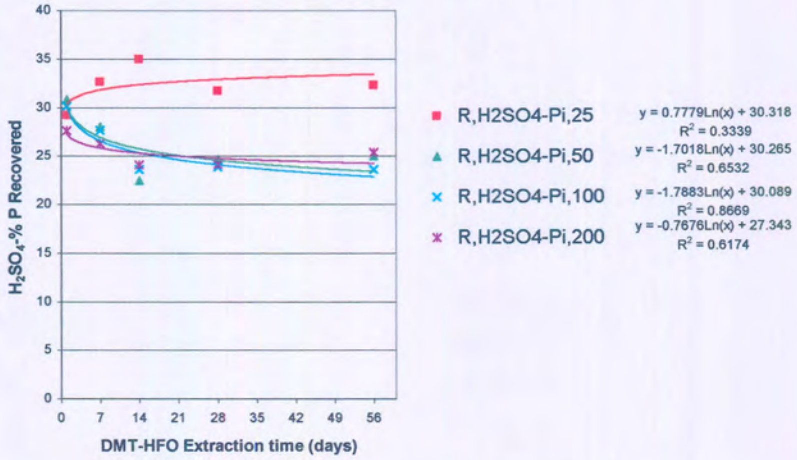

Fig. 17.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 240 days of incubation of Rustenburg soil

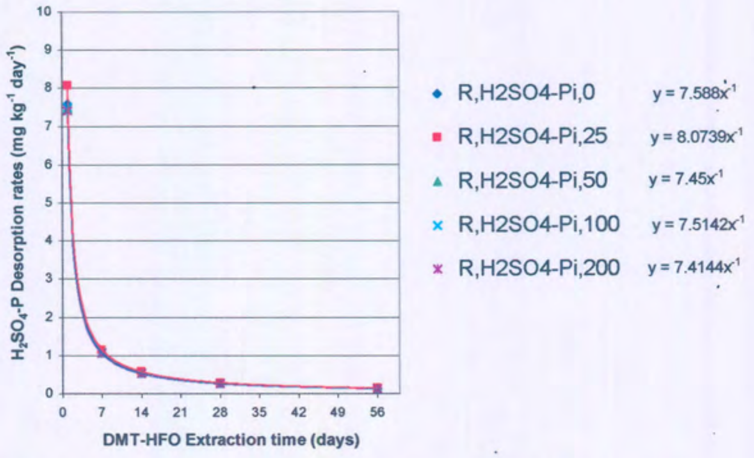

Fig. 17.2a. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates ($mg\ kg^{-1}\ day^{-1}$) after 1 day of incubation of Rustenburg soil

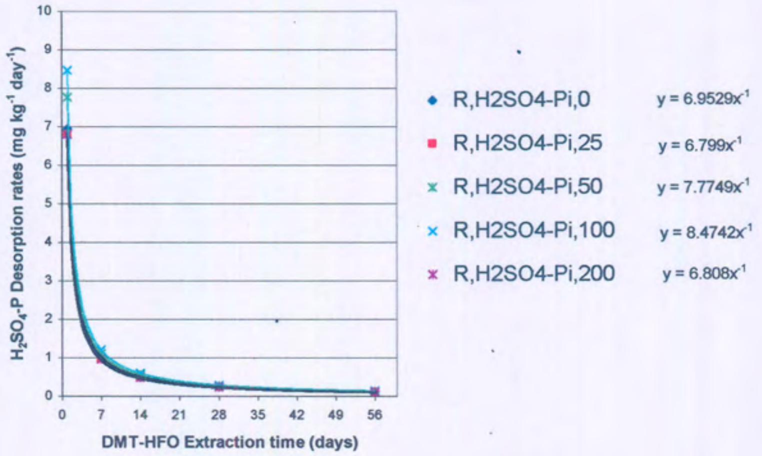

Fig. 17.2b. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates ($mg\ kg^{-1}\ day^{-1}$) after 120 days of incubation of Rustenburg soil

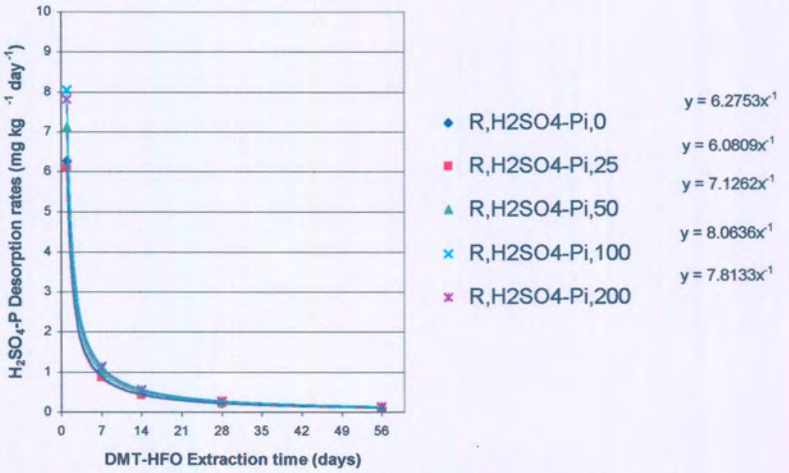

Fig. 17.2c. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates ($mg\ kg^{-1}\ day^{-1}$) after 240 days of incubation of Rustenburg soil

(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

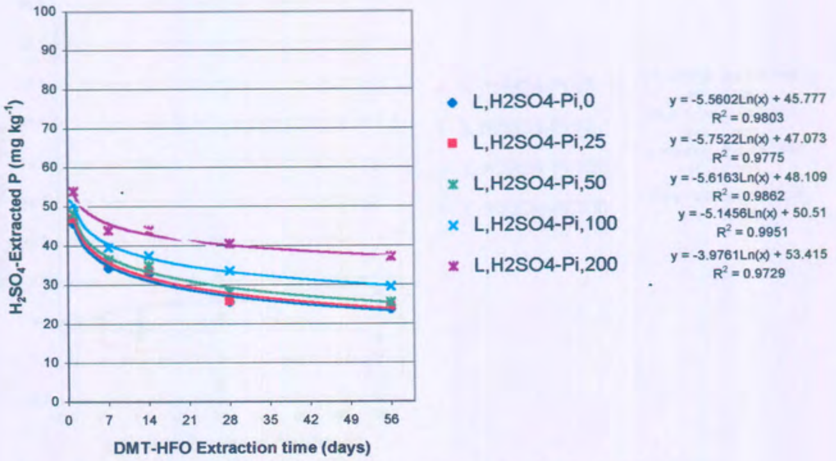

Fig. 18a. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 1 day of incubation of Loskop soil

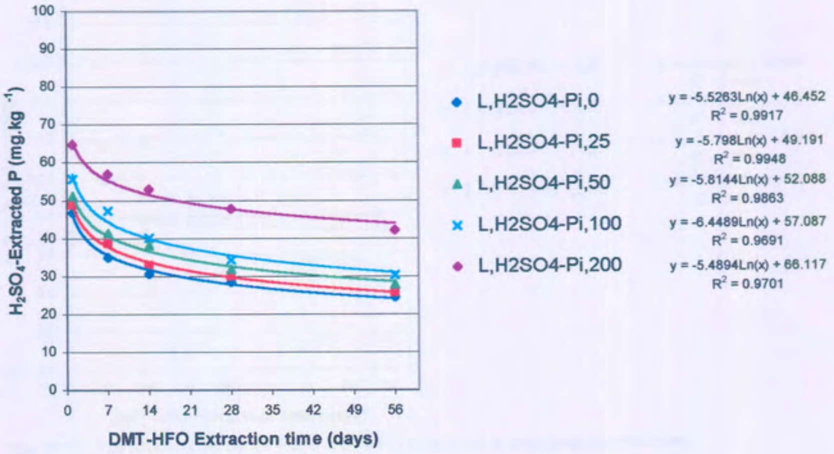

Fig. 18b. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 120 days of incubation of Loskop soil

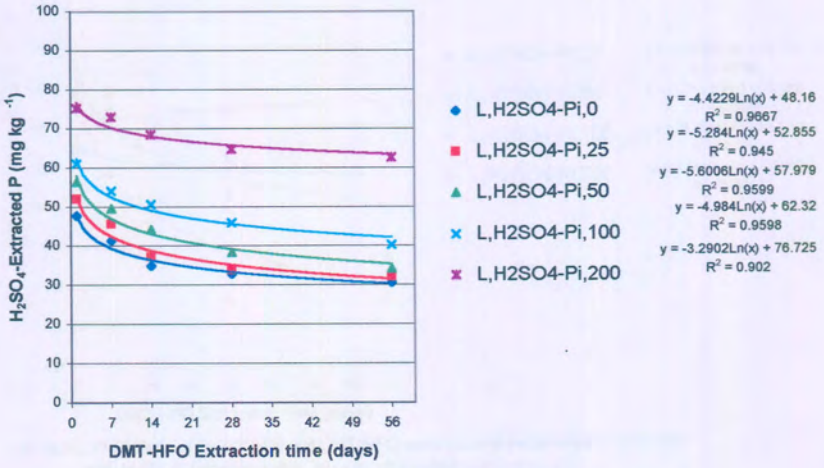

Fig. 18c. The effects of the added P and DMT-HFO extractions on the H_2SO_4-extractable P_i after 240 days of incubation of Loskop soil

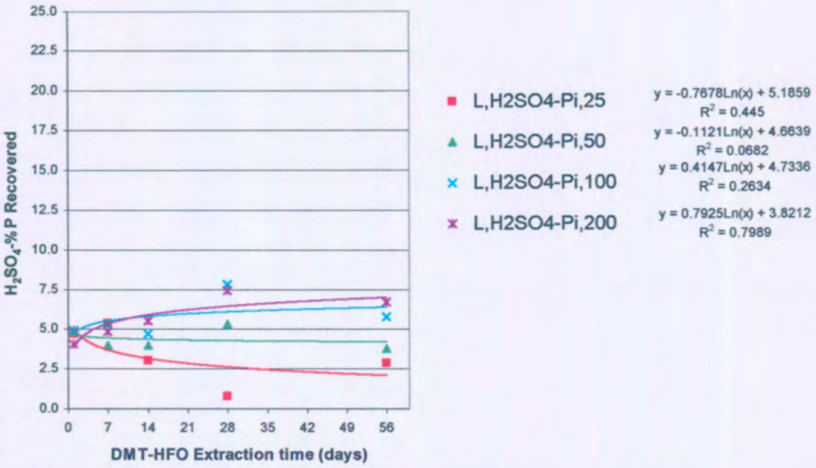

Fig. 18.1a. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 1 day of incubation of Loskop soil

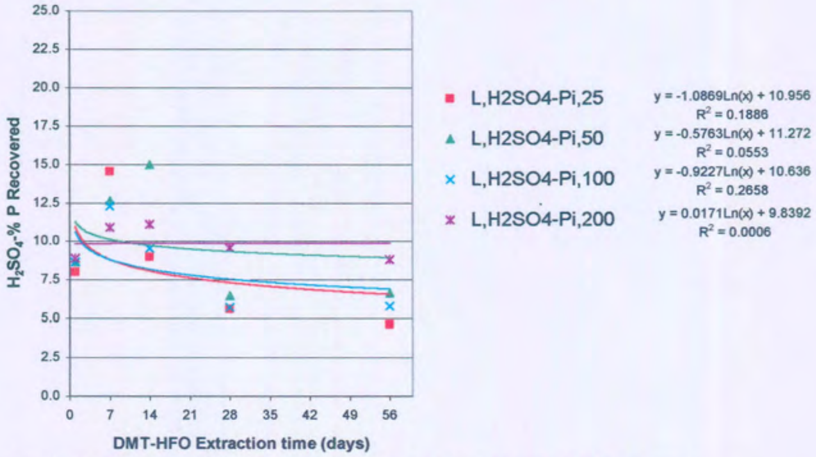

Fig. 18.1b. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 120 days of incubation of Loskop soil

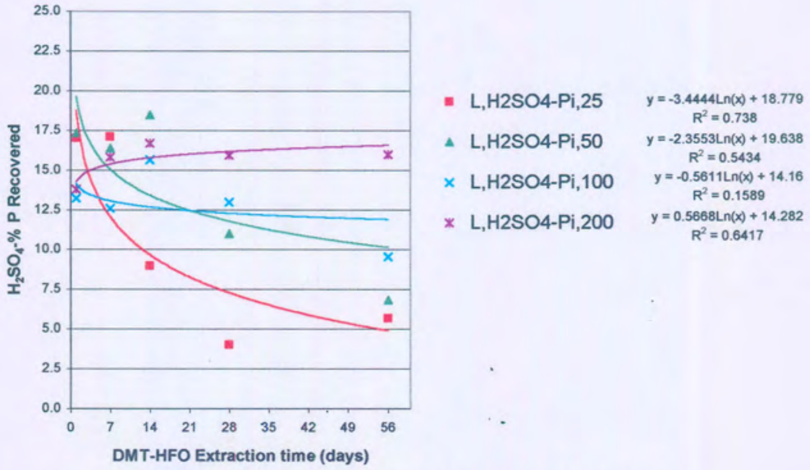

Fig. 18.1c. The effects of the added P and DMT-HFO extractions on percentage P_i recovered with H_2SO_4-P extractions after 240 days of incubation of Loskop soil

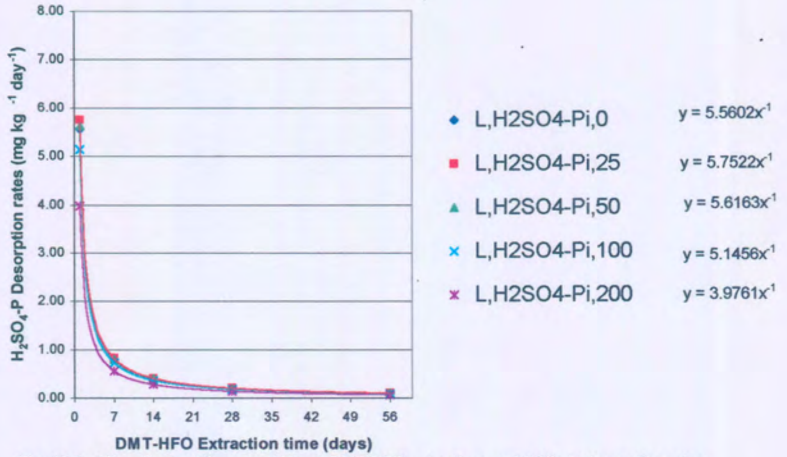

Fig. 18.2a. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

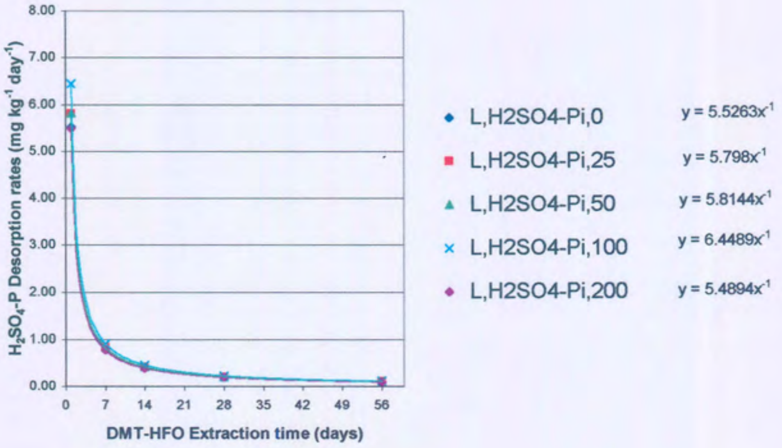

Fig. 18.2b. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 120 days of incubation of Loskop soil

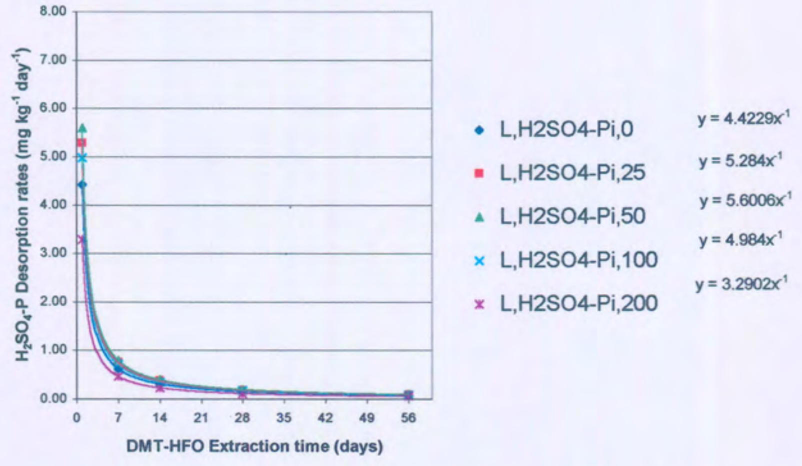

Fig. 18.2c. The effects of the added P and DMT-HFO extractions on H_2SO_4-P_i desorption rates (mg kg^{-1} day^{-1}) after 1 day of incubation of Loskop soil

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.

CHAPTER 5

LITERATURE CITED

1. ABRAMS, M.M. & JARRELL, M.M., 1992. Bio-availability index for phosphorus using ion exchange resins impregnated membranes. *Soil Sci. Soc. Am. J. 56, 1532 - 1537.*
2. ADEPETU, J.A. & COREY, R.B., 1976. Organic phosphorus as a predictor of plant-available phosphorus in soils of southern Nigeria. *Soil Sci. 122, 159 – 164.*
3. AMER, F., BOULDIN, D.R., BLACK, C.A. & DUKE, F.R., 1955. Characterization of soil phosphorus by anion exchange resin adsorption and ^{32}P equilibration *Plant Soil 6, 391 - 408.*
4. BACHE, B.W. & IRELAND, C., 1980. Desorption of phosphate from soils using anion exchange resins. *J. Soil Sci. 31, 297 - 306.*
5. BARBER, S.A., 1984. Soil nutrient bio-availability: A mechanistic approach. JOHN WILEY & SONS, NEW YORK.
6. BAINBRIDGE, S.H., MILES, N. & PRAAN, R., 1995. Phosphorus sorption in Natal soils. *S. Afri. J. Plant Soil 12, 59 - 64.*
7. BARROW, N.J., 1979. The description of desorption of phosphate from soil. *J. Soil Sci. 30, 259 - 270.*
8. BARROW, N.J., 1983. On the reversibility of phosphate sorption by soils. *J. Soil. Sci. 34, 751 – 758.*
9. BARROW, N.J. & SHAW, T.C., 1975a. The slow reactions between soil and anions: 2. The effects of time and temperature on the decrease in phosphate concentration in the soil solution. *Soil Sci. 119, 167 –177.*
10. BARROW, N.J. & SHAW, T.C., 1975b. The slow reactions between soil and anions: 3. The effects of time and temperature on the decrease in isotopically exchangeable phosphate. *Soil Sci. 119, 190 –197.*
11. BARROW, N.J. & SHAW, T.C., 1975c. The slow reactions between soil and anions: 4. Effects of period of prior contact on the desorption of phosphate from soils. *Soil Sci. 119, 311 –320.*

12. BARROW, N.J. & SHAW, T.C., 1977. Factors affecting the amount of phosphate extracted from soil by anion exchange resin. *Geoderma 18, 309–323.*

13. BASHOUR, I.I., DEVI PRASAD, J. & AL-JALOUD, A., 1985. Phosphorus fractionation in some soils of Saudi Arabia. *Geoderma, 36, 307 – 315.*

14. BLACK, C.A., Editor-in-Chief, EVANS, D.D., WHITE, J.L., ENSMINGER, L.E. CLARK, F.E., Associate Editors, 1965. Methods of Soil Analysis. Parts 1 and 2. Agronomy No.9. ASA, Madison, Wisconsin, USA.

15. BOTHA, A.D.P., SYNMAN, H.G., HAHNE, H.C.H., PRINSLOO A.L. STEENKAMP, C.J. & DU PLESSIS, D.P., 1968. Properties of the soils of the Tobacco and Cotton Research Institute. Department van Landbon – Tegnese Dienste, No. 74.

16. BOWMAN, R.A. & COLE, C.V., 1978. Transformations of organic phosphorus substrates in soils as evaluated by $NaHCO_3$ extraction. *Soil Sci. 125, 49 - 54.*

17. BOWMAN, R.A., RODRIGNEZ, J.B. & SELF, J.R., 1998. Comparison of methods to estimate occluded and resistant soil phosphorus. *Soil Sci. Soc. Am. J. 62, 338 - 342.*

18. BRADY, N.C., 1990. The Nature and Properties of Soils. 11th ed. MacMillan Publishing Co., NewYork.

19. BRAMLEY, R.G.V. & BARROW, N.J., 1992. The reaction between phosphate and dry soil. II. The effects of time, temperature and moisture status during incubation on the amount of plant available P. *Journal Soil Sci. 43, 759 – 766.*

20. BREWSTER, J.L., GANCHEVA, A.N. & NYE, P.H., 1975. The determination of desorption isotherms of soil phosphate using low volumes of solution and an anion exchange resin. *J. Soil Sci. 26, 364 - 377.*

21. CHANG, S.C. & JACKSON, M.L., 1957. Fractionation of soil phosphorus. *Soil Sci. 84, 133 - 144.*

22. CHAUHAN, B.S., STEWART, J.W.B. & PAUL, E.A., 1981. Effect of labile inorganic phosphate status and organic carbon additions on the microbial uptake of phosphorus in soils. *Can. J. Soil Sci. 61, 373-385.*

23. COOKE, I.J. & HISLOP, J., 1963. Use of anion exchange resin for the

assessment of available soil phosphate. *Soil Sci. 96, 308 - 312.*

24. COOKE, I.J., 1966. A kinetic approach to the desorption of soil phosphate status. *J. Soil Sci. 17, 56 – 64.*
25. COOPERBAND, L.R. & LOGAN, T.J., 1994. Measuring in-situ changes in labile soil phosphorus with anion - exchange membranes. *Soil Sci. Soc. Am. J. 58, 105 - 114.*
26. CUNNINGHAM, R.K., 1963. The effect of clearing a tropical rainforest. *J. Soil. Sci. 14, 334-345.*
27. DALAL, R.C., 1973. Characterization of soil inorganic phosphorus. I. Relationship of phosphorus to iron and aluminium. *Agrochim. 17, 385- 396.*
28. DALAL, R.C., 1977. Soil organic phosphorus. *Adv. Agron. 29, 83 - 113.*
29. DALAL, R.C., 1985.Comparative prediction of yield response and phosphorus uptake from soil using anion- and cation-exchange resins. *Soil Sci. 139, 227- 231.*
30. DALAL, R.C. & HALLSWORTH, E.G., 1976. Evaluation of parameters of soil phosphorus availability factors in predicting yield response and phosphorus uptake. *Soil Sci. Soc. Am. J. 40, 541 – 546.*
31. DEBNATH, N.C. & MANDAL, S.K., 1982. Evaluation of the relationship of inorganic phosphate fractions in soil with available phosphorus determined by some chemical and biological methods. *J. Indian Soc. Soil Sci. 30, 489 – 493.*
32. DOULA, M., A. IOANNOU, & DIMIRKOU, A., 1996. Thermodynamics of phosphate adsorption-desorption by Alfisols, Entisols, Vertisols, and Inceptisols. *Commu. Soil Sci. Plant Anal. 27, 1749 - 1764.*
33. du PREEZ, H.G. & CLAASSENS, A.S., 1999. Changes in inorganic and organic phosphorus in soil under maize (*Zea mays*) cultivation. *S. Afr. J. Plant Soil 16, 207 – 213.*
34. FAO/UNESCO, 1974. Soils Map of the World. Volume 1. : Legend. UNESCO, Paris.
35. FOX, R.L. & KAMPRATH, E.J., 1970. Phosphorus sorption isotherms for valuating the requirements of soils. *Soil Sci. Soc. Am. Proc. 34, 902 - 907.*
36. FREESE, D., LOOKMAN, R., MARKS, R. & VAN RIEMSDIJK, W.H., 1995.

New method for assessment of long-term phosphate esorption from soils. Soil. *Sci. Soc. Am. J. 59, 1295 - 1300.*

37. GENSTAT 5. , 1995. Release 3.2 Genstat for Windows. Laws Agricultural Trust, Rothamsted Experimental Station. Harpenden, Hertfordshire, U.K.
38. GERKE, J., 1992. Orthophosphate and organic phosphate in the soil solution of four sandy soils in relation to pH-evidence for humic- Fe- (Al-) phosphate complexes. *Commun. Soil Sci. Plant Anal. 23, 601 – 612.*
39. HAAS, H.J., GRUNES, D.L. & REICHMAN, G.A., 1961. Phosphorus changes in Great Plains soils as influenced by cropping and manure applications. *Soil Sci. Soc. Amer. Proc. 25, 215- 218.*
40. HAYNES, R.J., 1984. Lime and Phosphate in the soil - plant system. *Adv. Agron.37, 263 – 266.*
41. HEDLEY, M.J., STEWARD, J.W.B. & B.S. CHAUHAN, B.S., 1982. Changes in inorganic soil phosphorus fractions induced by cultivation practices and by laboratory incubation. *Soil Sci. Soc. Am. J. 46, 970 - 976.*
42. HINGSTON, F.J., POSNER, A.M. & QUIRK, J. P., 1974. Anion adsorption by goethite and gibbsite. II. Desorption of anions from hydrous oxide surfaces. *J. Soil Sci. 25, 16 -26.*
43. HOLFORD, I.C.R. & MATTINGLY, G.E.G., 1975. The high and low - energy phosphate adsorbing surfaces in calcareous soils. *J. Soil Sci. 26, 407 - 417.*
44. INDIATI, R., 1998. Changes in soil phosphorus extractability with successive removal of soil phosphate by iron-oxide-impregnated paper strips. *Commun. Soil Sci. Plant Anal. 29, 107 – 120.*
45. INDIATI, R., IZZA, C., FIGLIOLIA, A. & AMBROSELLI, R., 1992. Effetto della fertilizzazione fosfatica sul ool del fosforo inorganico. *Atti X onvegno Societa' Italiana di Chimica Agraria, Rome, Italy.*
46. INDIATI, R. & SHARPLEY, A.N., 1996. Release of soil phosphate by sequential extractions as a function of soil properties and added phosphorus. *Commun.Soil Sci. Plant Anal. 27, 2147-2157.*
47. INDIATI, R. & SHARPLEY, A.N., 1998. Changes in the distribution of inorganic soil phosphorus forms with phosphate desorption by iron oxide-

impregnated paper strips. *Commun. Soil Sci. Plant Anal. 29, 625 – 634.*

48. JOHNSTON, M.A., MILES, N. & THIABAU, G.R., 1991. Quantities of phosphorus fertilizer required to raise the soil test value. *S.Afr. J. Plant Soil 8, 7 - 21.*
49. KAFKAFI, U., POSNER, A.M. & QUIRK, J.P., 1967. Desorption of phosphate from kaolinite. *Soil Sci. Soc. Am. Proc. 31, 348-352.*
50. KAMPRATH, E.J., 1978. The role of soil chemistry in the diagnosis of nutrient disorders in tropical situations. Pp. 313 – 327. In: C.S. Andrew and E.J. Kamprath (eds.), Mineral Nutrition of Legumes in Tropical and Subtropical soils. CSIRO, Melbourne, Australia.
51. KAMPRATH, E.J., 1999. Changes in phosphate availability of Ultisols with long-term cropping. *Commun. Soil Sci. Plant Anal. 30, 909-919.*
52. LI, Y.C., ALVA, A.K., CALVERT, D.V. & BANKS, D., 1999. Transport of phosphorus and fractionation of residual phosphorus in various horizons of a Spodosol. *Water Air Soil Pollu. 109, 303 – 312.*
53. LINS, I.D.G., COX, F.R. & NICHOLAIDES, J.J., 1985. Optimizing phosphorus fertilization rates for soy beans grown on oxisols and associated Entisols. *Soi. Sci. Soc. Am. J. 49, 1457 – 1460.*
54. LINDSAY, W. L., VLEK, P.L.G. & CHIEN, S.H., 1989. Phosphate minerals. In: Minerals in soil environments.2nd Ed. Soil Science Society of America. Madison. Wis.
55. LOGANATHAN, P., ISIRIMAH, N.O. & NWACHUKU, D.A., 1987. Phosphorus sorption by Ultisols and Inceptisols of the Niger Delta in Southern Nigeria. *Soil Sci. 144, 330 - 338.*
56. LOGANATHAN, P. & SUTTON, P.M., 1987. Phosphorus fractions and availability in soils formed on different geological deposits in the Niger Delta area of Nigeria. *Soil Sci.143, 16 - 25.*
57. LOOKMAN, R., FREESE, D., MARKS, R., VLASSAK, K. & VAN RIEMSKDIJK, W.H., 1995. Long-term kinetics of phosphate release from the soil. *Environ. Sci. Technology. 29, 1569 - 1575.*
58. MADRID, L. & POSNER, A.M., 1979. Desorption of Phosphates from Geothite. *J. Soil Sci.30, 697 - 707.*

59. MCGEE, P.A.E., 1972. Phosphate adsorption in sesquioxic Transvaal soils. M.Sc. Thesis. University of Natal, Pietermaritzburg.

60. MCKEAN, S.J. & WARREN, G.P., 1996. Determination of phosphate desorption characteristics in soils using successive resin extractions. *Comun. Soil Sci .Plant Anal. 27, 2397 – 2417.*

61. MENON, R.G., CHIEN, C.S.H., HAMMOND, H.H. & ARORA, B.R., 1990. Sorption of phosphorus by the iron oxide impregnated filter paper (P_i soil test) embedded soils. *Plant Soil 126, 287 – 294.*

62. MICROSOFT EXCEL, 1995-1999. Microsoft Corporation. USA.

63. MOZAFFARI, M. & SIMS, J.T., 1994. Phosphorus availability and sorption in an Atlantic Coastal Plain watershed dominated by animal-based agriculture. *Soil Sci. 157, 97-107.*

64. MUNNS, D.N. & FOX, R.L., 1976. The slow reaction, which continues after phosphate sorption: Kinetics and equilibrium in some tropical soils. *Soil Sci. Soc. Am. J. 40, 46 – 51.*

65. MURPHY. J. & RILEY, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chem. Actal. 27, 31-36.*

66. NAGPAL. N. K., 1986. Effect of soil and effluent characteristics on phosphorus sorption in dosed columns. *J. Environ. Qual. 15, 73-78.*

67. NOVAIS, R. & KAMPRATH, E. J., 1978. Phosphorus supplying capacities of previously heavily fertilized soils. *Soil Sci. Soc. Am. J. 42, 931-935.*

68. OADES, J. & LADD, N., 1977. Biochemical properties: carbon and nitrogen metabolism.In: J.S.Russell, E.L. Greacen (ed.). Soil factors in crop production in semiarid environment. University of Queensland Press, Brisbane.

69. ONKEN, A.B. & MATHESON, R.L., 1982. Dissolution rate of EDTA-exchangeable phosphate from soils. *Soil Sci. Soc. Am. J. 46, 276 – 279.*

70. PAUTLER, M.C. & SIMS, J.T., 2000. Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Delaware soils. *Soil Sci. Soc. Am. J. 64, 765 – 773.*

71. PENN, M. R., AUER, M. T., VAN ORMAN, E. L. & KORIENEK, J. J., 1995. Phosphorus Diagenesis in Lake Sediments: Investigations using Fractionation

Techniques. *Mar. Freshwater Res., 1995, 46, 89-99.*

72. POTE, D.H., DANIEL, T.C., SHARPLEY, A.N., MOORE, P.A.Jr., EDWARDS, D.R. & NICHOLS, D.A., 1996. Relating extractable phosphorus in a silt loam to phosphorus loss in runoff. *Soil Sci. Soc. Am. J. 60, 855-859.*
73. POTE, D.H., DANIEL, T.C., NICHOLS, D.J., SHARPLEY, A.N., MOORE, P.A.JR., MILLER, D.M. & EDWARDS, D.R., 1998. Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. *J.Environ.Qual.28, 171-175.*
74. PUSHPARAJAH, E. & BACHIK, A.T., 1987. Management of acid tropical soils in South East Asia. In: Management of Acid Tropical Soils for Sustainable Agriculture. Proceedings of an IBSRAM inaugural workshop, Bangkok, Thailand.
75. QUANG, V.D., THAI, V.C., LINH, T.T.T., & DUFEY, J.E., 1996. Phosphorus sorption in soils of the Mekong Delta (Vietnam) as described by the Langmuir equation. *European Journal of Soil Science, 47, 113-123.*
76. RAVEN, K.P. & HOSSNER, L.R., 1994. Sorption and desorption quantity-intensity parameters to plant - available soil phosphorus. *Soil Sci. Am. J. 58, 405 - 410.*
77. REDDY, K.R., OVERCASH, M.R., KHALEEL, R. & WESTERMAN, P.W., 1980. Phosphorus adsorption- desorption characteristics of two soils utilized for disposal of animal wastes. *J. Environ. Qual. 15, 73- 78.*
78. REEVE, N.G. & SUMNER, M.E., 1970. Effects of aluminium toxicity and phosphorus fixation on crop growth on oxisols in Natal. *Soil Sci. Soc. Amer. Proc. 34, 263 - 267.*
79. REUTER, D.J., 1986. Temperate and Sub-tropical Crops. In: Reuter, D.J. and Robinson, J.B. (Ed.) Plant Analysis, An Interpretation Manual. Inkata Press. Melbourne, Australia. Pp 40-99.

80. RYDEN, J.C., MCLAUGHLIN, J.R. & SEYERS, J.K., 1977. Mechanics of phosphorus sorption of soils and hydrous ferric oxide gel. *J. Soil. Sci. 28, 72 – 92.*

81. SANCHEZ, P. A., 1976. Properties and Management of Soils in the Tropics. John Wiley & Sons, New York.

82. SANCHEZ, P. A. & SALINAS, J. G., 1981. Low input technology for managing Oxisols and Ultisols in Tropical America. *Adv. Agron. 34, 279-406.*

83. SANCHEZ, P.A., PALM, C.A. & SZOTH, L.T., 1991. Phosphorus dynamics in shifting cultivation systems in the Amazon. pp. 142 - 160. In: H. Tissen, D. Lopez-Hernandez, I.H. Salcedo (eds.). SCOPE - UNEP regional workshop 3: South and Central America. Institute of Pedology, Saskatoon, Canada.

84. SATTELL, R.R. & MORRIS, R.A., 1992. Phosphorus fractions and availability in Sri Lankan Alfisols. *Soil Sci. Soc. Am. J. 56, 1510 – 1515.*

85. SAWHNEY, B.L., 1977. Predicting phosphate movement through soil columns. *J.Environ. Qual. 6, 86 – 89.*

86. SAYIN, M., MERMUT, A.R. & TIESSEN, H., 1990. Phosphate sorption-desorption characteristics by magnetically separated soil fractions.*SoilSci.Soc. Am. J. 54, 1298 – 1304*

87. SHARMA, P.K., VERMA, S.P. & BHUMBLA, D.R., 1980. Transformation of added P into inorganic P fractions in some acid soils of Himachal Pradesh. *J. Indian Soc. Soil Sci. 28, 450 – 453.*

88. SHARPLEY, A.N., 1985. The cycling of phosphorus in unfertilized and fertilized agricultural soils. *Soil Sci. Soc. Am. J. 49, 905-911.*

89. SHARPLEY, A.N., 1987. Effect of phosphorus fertilizer on A values for soil cropped with winter wheat. *Plant and Soil 102, 201-205.*

90. SHARPLEY, A.N., 1996. Availability of residual phosphorus in manured soils. *Soil Sci. Soc. Am. J. 60, 1459-1466.*

91. SHARPLEY, A.N. & SISAK, I., 1997. The differential availability of manure and inorganic fertilizer phosphorus in soil. *Soil Sci. Soc. Am. J. 61, 1503-1508.*

92. SHARPLEY, A. N., SMITH, S.J., STEWART, B.A. & MATHERS, A.C., 1984. Phosphorus forms in soil receiving cattle feedlot waste. *J. Environ. Qual. 13, 211-215.*

93. SHARPLEY, A.N. & SMITH, S.J., 1985. Fractionation of inorganic and organic phosphorus in virgin and cultivated soils. *Soil Sci. Soc. Am. J. 49,1276-1300.*

94. SIBBESEN, E., 1978. A simple ion-exchange resin procedure for extracting plant available elements from soil. *Plant Soil 50, 305 - 321.*

95. SIBBESEN, E., 1983. Phosphate soil tests and their suitability to assess the phosphate status of soil. *J. Sci. Food Agric. 34, 1368 - 1374.*

96. SKOGLEY, E.O., GEORGITIS, S.J., YANG, E.J. & SCHAFF, B.E., 1990. The phytoavalability soil test - PST. *Commun. Soil Sci. Plant Anal. 21, 1229–1243.*

97. SOIL CLASSIFICATION WORKING GROUP, 1991. Soil Classification - A Taxonomic System for South Africa. Memoirs on the Agricultural Natural Resources of South Africa No. 5. Soil and Irrigation Research Institute Department of Agricultural Development, Pretoria.

98. STUANES, A. O. & ENFIELD, C.G., 1984. Prediction of phosphate movement through some selected soils. *J. environ. Qual. 13, 317-320.*

99. SYMITH, T.J. & SANCHEZ, P.A., 1980. Effects of lime silicate and phosphorus applications to an Oxisol on phosphorus sorption and ion rentention. *Soil. Sci. Soc. Am. J. 44, 500 –504.*

100. TEKALIGN, M. & HAQUE, J., 1991. Phosphorus status of some Ethiopian soils: Forms and distribution of inorganic phosphate and their relation to available phosphorus. *Trop. Agric. 68, 1-8.*

101. TIESSEN, H., J.W.B. SREWART, J.W.B. & COLE, C.V., 1984. Pathways of phosphorus transformation in soils of differing pedogenesis. *Soil Sci.Soc. Am. J. 48, 853 – 858.*

102. TIESSEN, H. & MOIR, J.O., 1993.Characterization of Available P by Sequential Extraction. Soil Sampling and Methods of Analysis. In: M.R. Caster. (Ed). Canadian Society of Soil Science. Lewis Publishers.

103. THOMAS, G. W. & PEASLEE, D.E., 1973. Testing soils for phosphorus. In: L.M. Walsh, J. D. Beaton (eds). Soil testing and plant analysis, revised edition. Soil Sci. Am. Madison, Wis.

104. UDO, E. J. & OGUNWALE, J.A., 1977. Phosphorus fractions in selected Nigerian Soils. *Soil Sci. Soc. Am. J. 41, 1141 - 1146.*

105. UNITED STATES DEPARTMENT OF AGRICULTURE, 1975. Soil Taxonomy.A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No 436. U.S. Government Printing Office, Washington, DC.

106. VAN DER ZEE, S.E.A.T.M. & VAN RIEMSDIJK, W.H., 1988. Model for long–term reaction kinetics in soil. *J. Environ. Qual. 17, 35 - 41.*

107. VAN DER ZEE, S.E.A.T.M. & GJALTEMA, A., 1992. Simulation of phosphate transport in soil columns. I. Model development. *Geoderma52,87 – 109.*

108. VAN RAIJ, B., QUAOGIO, J.A. & DA SILVA, N.M., 1986. Extraction of phosphorus, potassium, calcium and magnesium from soils by anion-exchange resin procedure. *Commun. Soil Sci. Plant Anal. 17, 547 – 566.*

109. VAN RIEMSDIJK, W.H., BOUMANS, L.J.M. & DE HAAN, F.A.M., 1984. Phosphate sorption by soils. I. A diffusion precipitation model for the reaction of phosphate with metal oxides in soil. *Soil Sci. Soc. Am. J. 48, 541 – 544.*

110. VAZQUEZ, N.E., NOELLEMYER, E. & COREMBERG, F., 1991. The dynamics of different organic and inorganic phosphorus fractions in soils from the south of Santa Fe province, Argentina. *Comm. Soil Sci. Plant Anal. 22, 1151- 1163.*

111. WAGER, B.I, STEWART, J.W.B. & MOIR, J.O., 1986. Changes with time in the form and availability of residual phosphorus on chernozemic soils. *Can. J. Soil Sci. 66, 105-119*

112. WALKER, T.W. & SYERS, J.K., 1976. The fate of phosphorus during

pedogenesis. *Geoderma 15, 1 – 19.*

113. WILLET, I.R., CHARTRES, C.J. & NGUYEN, T.T., 1988. Migration of phosphate into aggregated particles of ferrihydrite. *J. Soil Sci. 39, 275 - 282.*
114. WILLIAMS, J.D.H., SYERS, J.K. & WALKER, T.W., 1967. Fractionation of soil inorganic phosphate by a modification of Chang and Jackson's procedure. *Soil Sci. Soc. Am. Proc. 31, 736 – 739.*
115. YANG, J.E., E.O. SKOGLEY, E.O., 1992. Diffusion kinetics of multi-nutrient accumulation by mixed-bed ion-exchange resin. *Soil Sci. Soc. Am. J. 56, 408 – 411.*

CHAPTER 6

APPENDICES I

A: RUSTENBURG SOILS

1. The effects of P treatments and incubation time on the dialysis membrane tubes-hydrous ferric oxide extractable P (DMT-HFO-P_i) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	9313.57	716.43	2075.82	<.01
INC/PER (I/P)	4	7045.69	1761.42	5103.66	<.01
PHOSP.INC/PER (P.I/P)	52	3280.82	63.09	182.81	<.01
REPS.	2	0.18	0.09	0.25	
Residual	140	48.32	0.35		
Total	209	19688.39			

SE = 0.59; CV = 4.8

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	$Means^{1}$
0	2.50^{a}	2.87^{ab}	2.75^{ab}	2.58^{ab}	2.79^{ab}	2.70^{a}
5	4.84^{bc}	4.58^{bc}	4.00^{ab}	3.92^{ab}	4.02^{ab}	4.27^{b}
10	6.30^{c}	5.29^{bc}	4.17^{b}	4.00^{ab}	3.88^{ab}	4.73^{b}
20	9.42^{de}	6.09^{c}	4.83^{bc}	4.33^{bc}	4.17^{b}	5.77^{c}
25	9.73^{de}	6.08^{c}	5.65^{bc}	5.08^{bc}	4.63^{bc}	6.24^{d}
50	17.10^{hi}	6.92^{cd}	6.17^{c}	5.57^{bc}	5.79^{c}	8.31^{e}
75	23.85^{l}	7.33^{cd}	6.58^{c}	6.50^{c}	6.46^{c}	10.15^{f}
100	30.59^{m}	12.00^{f}	9.17^{de}	8.42^{d}	8.39^{d}	13.71^{g}
125	32.72^{n}	15.67^{h}	10.37^{e}	9.75^{de}	9.46^{de}	15.59^{h}
150	35.12^{p}	16.92^{hi}	13.23^{fg}	9.58^{de}	9.49^{de}	16.87^{i}
175	35.55^{p}	18.33^{i}	14.92^{gh}	10.38^{e}	10.88^{ef}	18.01^{j}
200	40.09^{q}	19.58^{j}	15.17^{gh}	14.00^{g}	12.59^{fg}	20.29^{k}
225	41.79^{r}	20.21^{jk}	16.33^{hi}	14.50^{gh}	13.79^{g}	21.33^{l}
250	42.01^{r}	21.37^{k}	17.75^{i}	17.08^{hi}	14.17^{gh}	22.48^{m}
$Means^{2}$	23.69^{d}	11.66^{c}	9.36^{b}	8.26^{a}	7.89^{a}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 0.72, I/P = 0.43, P.I/P = 1.61] for $Means^{1,2,3}$ respectively.

2. The effects of P treatments and incubation time on the 0.5M $NaHCO_3$ extractable inorganic P ($-HCO_3-P_i$) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	21577.76	1659.83	2697.76	<.01
INC/PER (I/P)	4	11056.34	2764.09	4492.53	<.01
PHOSP.INC/PER (P.I/P)	52	2720.79	52.32	85.04	<.01
REPS	2	3.41	1.71	2.85	
Residual	140	86.14	0.62		
Total	209	35441.03			

SE = 0.78; CV = 4.6

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^3	60^3	120^3	180^3	240^3	$Means^1$
0	6.30^{bc}	6.00^{bc}	4.20^{ab}	3.17^{ab}	2.90^{a}	4.51^{a}
5	8.87^{cd}	4.50^{ab}	3.50^{ab}	3.33^{ab}	3.46^{ab}	4.73^{a}
10	11.55^{de}	5.67^{bc}	3.83^{ab}	4.00^{ab}	4.04^{ab}	5.82^{b}
20	17.38^{g}	6.25^{bc}	4.75^{ab}	4.42^{ab}	4.21^{ab}	7.40^{c}
25	17.42^{g}	7.58^{c}	5.17^{b}	4.67^{ab}	4.42^{ab}	7.85^{c}
50	25.99^{j}	13.75^{ef}	8.08^{cd}	5.92^{bc}	5.63^{bc}	11.87^{d}
75	27.32^{j}	16.33^{fg}	10.00^{d}	8.42^{cd}	8.09^{cd}	14.03^{e}
100	32.00^{k}	18.08^{g}	12.50^{e}	9.92^{d}	9.71^{cd}	16.44^{f}
125	35.93^{l}	20.92^{h}	18.25^{gh}	15.00^{f}	12.54^{e}	20.53^{g}
150	51.89^{n}	24.08^{ij}	20.33^{h}	15.58^{fg}	15.38^{fg}	25.45^{h}
175	53.96^{n}	25.17^{ij}	21.17^{h}	17.92^{g}	16.00^{fg}	26.84^{i}
200	67.13^{p}	31.25^{k}	23.58^{i}	20.92^{h}	19.25^{gh}	32.43^{j}
225	75.51^{q}	34.83^{l}	24.50^{ij}	26.50^{j}	21.46^{hi}	36.56^{k}
250	77.44^{q}	38.50^{m}	26.83^{j}	27.22^{j}	23.75^{i}	38.75^{l}
$Means^2$	36.34^{e}	18.07^{d}	13.34^{c}	11.93^{b}	10.88^{a}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 0.96, I/P = 0.58, P.I/P = 2.15] for Means ^{1,2,3} respectively.

3. The effects of P treatments and incubation period on the 0.5m $NaHCO_3$ extractable organic P ($-HCO_3-P_o$) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PHOSP (P)	13	1739.00	133.77	161.78	<.01
INC/PER (I/P)	4	5913.93	1478.48	1788.10	<.01
PHOSP.INC/PER (P.I/P)	52	554.75	10.67	12.90	<.01
REPS.	2	4.44	2.22	2.75	
Residual	140	115.76	0.83		
Total	209	8323.43			

SE = 0.91; CV = 6.8

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^3	60^3	120^3	180^3	240^3	Means^1
0	10.00^{bc}	10.00^{bc}	11.00^{cd}	5.08^{ab}	4.86^{a}	8.19^{a}
5	10.23^{cd}	11.83^{cd}	12.67^{d}	5.33^{ab}	5.04^{ab}	9.02^{ab}
10	10.80^{cd}	12.42^{cd}	13.08^{d}	6.17^{ab}	5.29^{ab}	9.55^{b}
20	11.13^{cd}	13.75^{de}	13.83^{de}	6.17^{ab}	5.96^{ab}	10.17^{b}
25	10.47^{cd}	14.75^{de}	15.00^{de}	6.92^{ab}	6.00^{ab}	10.63^{b}
50	10.72^{cd}	18.17^{ef}	17.67^{ef}	7.33^{ab}	6.46^{ab}	12.07^{c}
75	10.48^{cd}	20.50^{fg}	19.67^{f}	7.92^{bc}	6.59^{ab}	13.03^{cd}
100	11.37^{cd}	22.67^{g}	19.33^{f}	8.33^{bc}	6.88^{ab}	13.72^{d}
125	11.50^{cd}	23.50^{gh}	19.42^{f}	8.33^{bc}	6.96^{ab}	13.94^{d}
150	11.77^{cd}	24.00^{gh}	21.50^{fg}	8.67^{bc}	7.29^{ab}	14.65^{de}
175	11.97^{cd}	26.00^{h}	22.50^{g}	10.17^{cd}	7.50^{b}	15.63^{e}
200	12.90^{d}	26.17^{h}	23.00^{gh}	13.08^{d}	9.00^{bc}	16.83^{f}
225	16.17^{e}	26.37^{h}	24.00^{gh}	13.67^{de}	10.04^{c}	18.05^{g}
250	16.63^{e}	26.50^{h}	25.50^{h}	15.78^{e}	13.75^{de}	19.63^{h}
Means^2	1.87^{c}	19.76^{e}	18.44^{d}	8.78^{b}	7.26^{a}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.12, I/P = 0.67, P.I/P = 2.50] for Means ^{1,2,3} respectively.

4. The effects of added P and incubation period on the 0.1M NaOH extractable inorganic P (-OH-P_i) of Rustenburg soil.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	64062.48	4927.88	1559.37	<.01
INC/PER (I/P)	4	33278.94	8319.74	2632.69	<.01
PHOSP.INC/PER (P.I/P)	52	6923.16	133.14	42.13	<.01
REPS	2	6.17	3.08	0.98	
Residual	140	442.42	3.16		
Total	209	104707.02			

SE = 1.78; CV = 2.6

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	30.00^{a}	34.33^{ab}	43.42^{cd}	44.08^{cd}	46.70^{d}	39.71^{a}
5	35.80^{b}	38.83^{bc}	44.08^{cd}	47.33^{de}	47.00^{d}	42.61^{b}
10	36.60^{b}	40.33^{bc}	45.67^{cd}	51.00^{d}	50.33^{de}	44.79^{bc}
20	37.73^{bc}	41.50^{c}	46.67^{d}	52.17^{e}	53.00^{e}	46.21^{c}
25	38.80^{bc}	42.00^{cd}	48.25^{de}	52.17^{e}	53.67^{e}	46.98^{c}
50	39.37^{bc}	52.08^{e}	54.17^{e}	60.00^{f}	63.33^{fg}	53.79^{d}
75	40.47^{bc}	63.83^{fg}	68.67^{gh}	71.17^{h}	70.33^{gh}	62.89^{e}
100	61.03^{f}	69.33^{gh}	72.00^{h}	78.67^{i}	80.00^{ij}	72.21^{f}
125	66.00^{g}	83.50^{ij}	83.33^{ij}	85.33^{j}	85.67^{j}	80.77^{g}
150	68.20^{gh}	83.67^{j}	85.25^{j}	87.17^{j}	93.00^{k}	83.46^{h}
175	70.30^{gh}	84.42^{j}	95.33^{kl}	98.67^{lm}	103.00^{m}	90.34^{i}
200	82.53^{ij}	94.42^{kl}	98.00^{l}	103.00^{m}	104.00^{m}	96.39^{j}
225	86.33^{j}	97.33^{kl}	102.00^{lm}	103.83^{lm}	105.33^{m}	98.76^{k}
250	87.10^{j}	102.58^{lm}	105.17^{m}	105.33^{m}	107.00^{m}	101.44^{l}
Means^{2}	55.73^{a}	66.30^{b}	70.86^{c}	74.21^{d}	75.88^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 2.18, I/P = 1.30, P.I/P = 4.88] for Means ^{1,2,3} respectively.

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5. The effects of P treatments and incubation period on the 0.1M NaOH extractable organic P (-OH-P_o) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	6402.45	492.50	376.21	<.01
INC/PER (I/P)	4	2737.93	684.48	522.86	<.01
PHOSP.INC/PER (P.I/P)	52	1494.53	28.74	21.95	<.01
REPS.	2	15.20	7.60	6.24	
Residual	140	183.28	1.31		
Total	209	10818.19			

SE = 1.14; CV = 5.2

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^3	60^3	120^3	180^3	240^3	Means^1
0	13.80^{ab}	14.17^{ab}	15.21^{ab}	13.33^{ab}	12.42^{a}	13.79^{a}
5	13.97^{ab}	14.75^{ab}	15.96^{b}	14.17^{ab}	13.00^{ab}	14.37^{ab}
10	13.93^{ab}	14.84^{ab}	16.17^{b}	15.33^{ab}	13.08^{ab}	14.67^{ab}
20	14.40^{ab}	15.09^{ab}	17.08^{bc}	15.58^{b}	13.83^{ab}	15.40^{b}
25	14.47^{ab}	16.34^{b}	17.25^{bc}	16.67^{bc}	15.00^{ab}	15.95^{b}
50	14.97^{ab}	20.63^{cd}	22.33^{cd}	20.00^{c}	17.08^{bc}	19.00^{c}
75	14.80^{ab}	20.75^{cd}	23.50^{d}	21.58^{cd}	19.67^{c}	20.06^{c}
100	15.10^{ab}	24.25^{de}	25.58^{de}	22.33^{cd}	20.33^{cd}	21.52^{d}
125	16.03^{b}	25.25^{de}	25.75^{de}	23.25^{d}	21.58^{cd}	22.37^{de}
150	15.90^{b}	25.92^{de}	26.88^{e}	24.50^{de}	23.17^{d}	23.27^{e}
175	15.67^{b}	26.13^{e}	27.93^{e}	25.75^{de}	24.00^{de}	24.50^{e}
200	15.97^{b}	26.79^{e}	28.08^{e}	26.17^{de}	24.83^{de}	24.37^{e}
225	21.67^{cd}	27.17^{e}	28.25^{e}	27.25^{e}	26.08^{de}	26.08^{f}
250	24.90^{de}	28.38^{e}	28.92^{e}	28.67^{e}	26.00^{de}	27.37^{f}
Means^2	16.18^{a}	21.68^{d}	22.78^{e}	21.04^{c}	19.29^{b}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.40, I/P = 0.84, P.I/P = 3.14] for Means ^{1,2,3} respectively.

6. The effects of P treatments and incubation on the 1M HCl extractable Ca - bound P (D/HCl-P_i) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	6912.10	531.70	755.36	<.01
INC/PER (I/P)	4	1990.17	497.54	706.84	<.01
PHOSP.INC/PER (P.I/P)	52	522.16	10.04	14.27	<.01
REPS.	2	3.42	1.72	2.48	
Residual	140	98.55	0.70		
Total	209	9522.97			

SE = 0.84; CV = 4.7

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	6.73^{a}	6.92^{ab}	7.25^{ab}	8.00^{ab}	8.85^{ab}	7.55^{a}
5	6.79^{ab}	7.33^{ab}	8.17^{ab}	8.17^{ab}	9.00^{ab}	7.89^{ab}
10	6.84^{ab}	8.17^{ab}	8.50^{ab}	9.67^{b}	10.97^{bc}	8.83^{b}
20	6.97^{ab}	9.08^{b}	9.80^{b}	10.50^{bc}	12.92^{cd}	9.85^{b}
25	7.14^{ab}	9.42^{b}	10.17^{b}	12.33^{c}	13.33^{cd}	10.48^{c}
50	9.76^{b}	12.33^{c}	13.21^{cd}	15.17^{de}	16.92^{de}	13.48^{d}
75	12.30^{c}	13.17^{cd}	14.67^{d}	17.33^{e}	18.42^{ef}	15.18^{e}
100	13.40^{cd}	15.08^{de}	16.08^{de}	18.17^{ef}	20.33^{fg}	16.61^{f}
125	13.72^{cd}	16.58^{de}	17.29^{e}	20.50^{fg}	22.58^{g}	18.13^{g}
150	14.05^{cd}	17.58^{e}	18.92^{ef}	21.83^{fg}	23.75^{gh}	19.23^{h}
175	14.50^{cd}	18.93^{ef}	20.17^{f}	23.00^{g}	25.92^{h}	20.50^{i}
200	15.07^{de}	19.92^{f}	22.04^{fg}	24.83^{gh}	27.17^{hi}	21.81^{j}
225	19.40^{ef}	22.75^{g}	24.58^{gh}	25.33^{h}	28.92^{i}	24.20^{k}
250	21.40^{fg}	24.67^{gh}	24.83^{gh}	29.67^{i}	30.67^{i}	26.25^{l}
Means^{2}	12.01^{a}	14.42^{b}	15.41^{c}	17.46^{d}	19.27^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.03, I/P = 0.62, P.I/P = 2.30] for Means ^{1,2,3} respectively.

7. The effects of added P and incubation period on the conc. HCl digestible inorganic P (C/HCl-P_i) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	25784.60	1983.43	678.03	<.01
INC/PER (I/P)	4	33602.61	8400.65	2871.74	<.01
PHOSP.INC/PER (P.I/P)	52	14049.55	270.18	92.36	<.01
REPS.	2	32.64	16.32	5.98	
Residual	140	409.54	2.92		
Total	209	73846.30			

SE = 1.71; CV = 2.3

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	50.93^{a}	58.00^{bc}	58.33^{bc}	59.00^{bc}	59.60^{bc}	57.17^{a}
5	50.93^{a}	58.67^{bc}	58.33^{bc}	59.67^{bc}	59.95^{bc}	57.51^{a}
10	50.93^{a}	59.33^{bc}	60.23^{bc}	59.67^{bc}	60.43^{c}	58.12^{ab}
20	51.10^{ab}	59.67^{bc}	61.00^{cd}	60.33^{c}	60.94^{c}	58.61^{ab}
25	51.60^{ab}	60.00^{bc}	61.33^{cd}	62.33^{cd}	64.62^{cd}	59.98^{b}
50	53.83^{ab}	62.33^{cd}	65.00^{cd}	68.67^{de}	70.67^{e}	64.10^{c}
75	55.63^{b}	63.67^{cd}	70.67^{e}	71.33^{ef}	78.54^{fg}	67.97^{d}
100	56.93^{bc}	65.67^{d}	76.00^{fg}	78.67^{fg}	80.10^{fg}	71.47^{e}
125	57.73^{bc}	68.67^{de}	77.33^{fg}	80.33^{g}	87.08^{hi}	74.23^{f}
150	60.97^{c}	70.33^{de}	80.67^{g}	86.00^{h}	89.96^{hi}	77.59^{g}
175	61.67^{cd}	72.67^{ef}	89.00^{hi}	91.00^{ij}	94.02^{ij}	81.67^{h}
200	63.73^{cd}	75.33^{ef}	93.00^{i}	98.00^{j}	100.54^{jk}	86.12^{i}
225	69.87^{de}	89.33^{hi}	93.67^{ij}	103.67^{k}	105.12^{k}	92.33^{j}
250	75.47^{f}	93.00^{i}	95.00^{ij}	106.00^{k}	107.48^{k}	95.39^{k}
Means^{2}	57.95^{a}	68.33^{b}	74.25^{c}	77.48^{d}	79.93^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 2.10, I/P = 1.26, P.I/P =4.69] for Means ^{1,2,3} respectively.

8. The effects of P treatments and incubation period on the conc. HCl digestible organic P ($C/HCl\text{-}P_o$) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1622.48	124.81	67.54	<.01
INC/PER (I/P)	4	1408.38	352.10	190.54	<.01
PHOSP.INC/PER (P.I/P)	52	417.73	8.03	4.35	<.01
REPS.	2	0.90	0.45	0.24	
Residual	140	258.71	1.85		
Total	209	3707.30			

SE = 1.36; CV = 7.8

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	9.67^{a}	11.75^{ab}	12.83^{ab}	13.33^{ab}	13.52^{b}	12.22^{a}
5	9.70^{a}	11.83^{ab}	12.83^{ab}	13.67^{b}	14.88^{bc}	12.58^{a}
10	9.70^{a}	11.92^{ab}	12.90^{ab}	13.67^{b}	15.77^{bc}	12.97^{a}
20	9.70^{a}	11.92^{ab}	13.00^{ab}	14.00^{bc}	16.68^{bc}	13.06^{a}
25	9.73^{a}	12.17^{ab}	13.17^{ab}	14.60^{bc}	16.71^{bc}	13.28^{ab}
50	10.10^{ab}	13.50^{b}	15.00^{bc}	16.40^{bc}	19.21^{cd}	14.84^{b}
75	10.30^{ab}	15.92^{bc}	16.33^{bc}	18.33^{cd}	19.87^{cd}	16.15^{bc}
100	10.50^{ab}	16.25^{bc}	18.50^{cd}	18.67^{cd}	20.52^{cd}	16.89^{c}
125	13.60^{b}	17.42^{c}	18.67^{cd}	19.00^{cd}	21.67^{d}	18.07^{cd}
150	13.65^{b}	17.93^{cd}	19.00^{cd}	20.00^{cd}	21.75^{d}	18.47^{cd}
175	13.70^{bc}	18.83^{cd}	19.67^{cd}	20.33^{cd}	23.35^{de}	19.24^{d}
200	13.80^{bc}	19.25^{cd}	20.67^{cd}	21.33^{d}	23.67^{de}	19.74^{de}
225	14.47^{bc}	21.25^{d}	20.33^{cd}	25.67^{e}	24.24^{de}	21.19^{e}
250	14.53^{bc}	22.42^{d}	20.33^{cd}	29.33^{e}	29.35^{e}	23.19^{f}
Means^{2}	11.68^{a}	15.88^{b}	16.66^{b}	18.45^{c}	20.09^{d}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.67, I/P = 1.00, P.I/P = 3.73] for Means ^{1,2,3} respectively.

9. The Effects of added P and incubation period on the conc.H_2SO_4 and H_2O_2 digestible P (H_2SO_4-P_i) of Rustenburg soil.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	18143.74	1395.67	530.63	<.01
INC/PER (I/P)	4	18232.71	558.18	1733.01	<.01
PHOSP.INC/PER (P.I/P)	52	5166.26	99.35	37.77	<.01
REPS.	2	15.47	7.74	3.03	
Residual	140	368.23	2.63		
Total	209	41910.95			

SE = 1.62; CV = 2.3

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	55.27^{a}	55.73^{ab}	56.50^{ab}	60.67^{bc}	61.83^{bc}	58.00^{a}
5	55.88^{ab}	56.00^{ab}	58.17^{ab}	60.83^{bc}	64.00^{bc}	58.98^{a}
10	56.00^{ab}	56.33^{ab}	58.33^{ab}	61.00^{bc}	64.58^{bc}	59.25^{a}
20	56.00^{ab}	56.33^{ab}	58.57^{ab}	61.67^{bc}	64.58^{bc}	59.43^{a}
25	56.17^{ab}	56.67^{ab}	58.83^{ab}	62.00^{bc}	65.67^{c}	59.87^{a}
50	56.83^{ab}	59.00^{ab}	65.67^{c}	67.67^{cd}	70.17^{d}	63.87^{b}
75	56.93^{ab}	61.33^{bc}	72.83^{de}	70.67^{d}	75.17^{e}	67.39^{c}
100	57.33^{ab}	65.22^{c}	74.17^{de}	73.67^{de}	78.58^{ef}	69.79^{d}
125	57.50^{ab}	64.88^{c}	75.50^{e}	81.33^{f}	89.42^{gh}	73.73^{e}
150	59.50^{ab}	72.38^{de}	80.17^{f}	86.67^{g}	89.67^{gh}	77.68^{f}
175	60.17^{b}	76.33^{ef}	86.67^{g}	93.00^{h}	96.00^{hi}	82.43^{g}
200	61.67^{bc}	80.47^{f}	89.50^{gh}	93.33^{h}	99.17^{i}	84.83^{h}
225	67.83^{cd}	87.17^{g}	93.33^{h}	94.33^{h}	105.08^{j}	89.55^{i}
250	69.00^{cd}	88.08^{g}	94.17^{h}	94.67^{h}	106.50^{j}	90.48^{i}
Means^{2}	59.01^{a}	66.85^{b}	73.03^{c}	75.82^{d}	80.74^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.99, I/P = 1.19, P.I/P = 4.45] for Means ^{1,2,3} respectively.

10. The effects of P treatments and incubation periods on the total inorganic P (HFO-P_i + HCO_3-P_i + OH-P_i + conc. HCl-P_i + conc. H_2SO_4-P_i) ($TOTP_i$) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	746010.18	57385.40	4738.96	<.01
INC/PER (I/P)	4	123948.14	30987.03	2558.95	<.01
PHOSP.INC/PER (P.I/P)	52	27741.92	533.50	44.06	<.01
REPS.	2	218.61	109.31	10.21	
Residual	140	1695.30	12.11		
Total	209	899395.54			

SE = 3.48; CV = 1.3

(ii) Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	158.74^{a}	167.85^{ab}	172.45^{bc}	177.50^{bc}	180.47^{c}	171.40^{a}
5	165.04^{ab}	171.92^{bc}	183.25^{c}	188.75^{cd}	188.42^{cd}	179.48^{b}
10	168.52^{b}	184.12^{c}	195.97^{d}	208.00^{ef}	199.23^{de}	191.17^{c}
20	185.60^{c}	196.92^{d}	199.38^{de}	224.75^{fg}	220.82^{fg}	205.49^{d}
25	186.86^{cd}	199.75^{de}	210.40^{ef}	230.58^{gh}	238.34^{h}	213.19^{e}
50	206.88^{e}	217.42^{f}	236.29^{gh}	255.98^{i}	261.50^{i}	235.62^{f}
75	215.91^{ef}	245.67^{h}	264.42^{ij}	282.42^{kl}	281.01^{k}	257.88^{g}
100	235.29^{g}	262.38^{ij}	273.92^{jk}	293.50^{lm}	297.12^{lm}	272.44^{h}
125	243.61^{h}	278.22^{jk}	286.08^{kl}	309.25^{mn}	318.75^{np}	287.18^{i}
150	252.73^{i}	283.97^{kl}	308.57^{mn}	324.83^{p}	333.34^{pq}	300.69^{j}
175	268.14^{ij}	298.85^{lm}	313.25^{n}	343.97^{q}	345.81^{q}	314.00^{k}
200	271.22^{j}	307.97^{mn}	338.29^{q}	362.08^{rs}	370.71^{s}	330.05^{l}
225	290.73^{l}	321.63^{np}	347.42^{qr}	371.17^{s}	384.71^{tu}	343.13^{m}
250	302.42^{m}	338.20^{q}	356.75^{r}	381.97^{t}	391.56^{u}	354.18^{n}
Means^{2}	225.12^{a}	248.20^{b}	263.32^{c}	282.48^{d}	286.56^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 4.27, I/P = 2.55, P.I/P = 9.55] for Means ^{1,2,3} respectively.

11. The effects of P treatments and incubation period on the total organic P (HCO_3-P_o + OH-P_o + conc. HCl-P_o) (TOT-P_o) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	26028.06	2002.16	493.92	<.01
INC/PER (I/P)	4	12693.95	3173.49	782.88	<.01
PHOSP.INC/PER (P.I/P)	52	3748.98	72.10	17.79	<.01
REPS.	2	24.80	12.40	3.15	
Residual	140	567.51	4.05		
Total	209	43038.50			

SE = 2.01; CV = 3.8

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^3	60^3	120^3	180^3	240^3	Means^1
0	34.47^{bc}	36.92^{bc}	38.05^{bc}	29.75^{ab}	25.80^{a}	33.00^{a}
5	36.53^{bc}	39.42^{cd}	40.96^{cd}	33.17^{b}	28.93^{ab}	35.80^{b}
10	37.13^{bc}	51.17^{ef}	43.85^{d}	40.17^{cd}	34.15^{bc}	41.29^{c}
20	37.93^{bc}	53.75^{ef}	44.92^{d}	46.75^{de}	39.47^{cd}	44.56^{d}
25	37.67^{bc}	57.17^{f}	50.42^{e}	49.18^{de}	42.21^{cd}	47.33^{e}
50	38.78^{c}	58.30^{fg}	61.00^{fg}	51.73^{ef}	46.75^{de}	51.31^{f}
75	38.58^{bc}	60.17^{fg}	62.50^{fg}	52.83^{ef}	50.13^{de}	52.84^{g}
100	39.97^{cd}	64.17^{gh}	65.42^{gh}	55.33^{ef}	50.73^{ef}	55.12^{h}
125	41.13^{cd}	67.17^{gh}	65.83^{gh}	55.58^{ef}	54.42^{ef}	56.83^{hi}
150	41.70^{cd}	72.85^{hi}	66.38^{gh}	57.17^{f}	54.21^{ef}	58.46^{i}
175	41.13^{cd}	73.96^{hi}	68.10^{gh}	59.25^{fg}	56.85^{ef}	59.86^{i}
200	42.67^{cd}	78.21^{i}	68.75^{gh}	63.58^{g}	58.51^{fg}	62.34^{j}
225	52.30^{ef}	83.78^{j}	69.58^{h}	72.58^{h}	60.36^{fg}	67.72^{k}
250	56.07^{f}	86.29^{j}	72.75^{hi}	81.78^{ij}	69.10^{gh}	73.20^{l}
Means^2	41.15^{a}	63.10^{e}	58.47^{d}	53.49^{c}	47.97^{b}	

N.B. Means with the same superscripts are not significantly different (P =0.01) LSD (Fisher) [P = 2.47, I/P = 1.48, P.I/P = 5.53]for Means ^{1,2,3} respectively.

12. The effects of P treatments and incubation periods on the total soil P (Total-P_i + Total-P_o) (TOT-P) of Rustenburg soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1045116.21	80393.55	5893.82	<.01
INC/PER (I/P)	4	156966.81	39241.70	2876.89	<.01
PHOSP.INC/PER (P.I/P)	52	42480.92	816.94	59.89	<.01
REPS.	2	326.85	163.43	14.25	
Residual	140	1909.64	13.64		
Total	209	1246473.58			

SE = 3.69; CV = 1.2

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60	120^{3}	180^{3}	240^{3}	Means^{1}
0	193.20^{a}	204.77^{b}	210.50^{bc}	207.25^{bc}	206.27^{b}	204.40^{a}
5	201.58^{ab}	211.34^{bc}	224.21^{cd}	221.92^{c}	217.35^{c}	215.28^{b}
10	205.65^{b}	235.29^{d}	240.82^{de}	248.17^{ef}	233.38^{d}	232.66^{c}
20	224.53^{cd}	250.67^{ef}	243.30^{de}	271.50^{g}	260.29^{fg}	250.06^{d}
25	224.53^{cd}	256.92^{f}	260.82^{fg}	279.77^{h}	280.55^{h}	260.52^{e}
50	245.67^{e}	275.71^{gh}	297.29^{ij}	307.72^{j}	308.25^{j}	286.93^{f}
75	254.49^{ef}	305.84^{j}	331.92^{kl}	335.25^{kl}	331.13^{kl}	311.73^{g}
100	275.25^{gh}	326.55^{k}	339.33^{l}	348.83^{lm}	347.85^{lm}	327.56^{h}
125	284.74^{h}	345.39^{lm}	351.91^{m}	364.83^{n}	373.17^{np}	344.01^{i}
150	294.43^{i}	356.82^{mn}	374.94^{np}	382.00^{p}	387.55^{p}	359.15^{j}
175	306.28^{j}	372.81^{np}	381.35^{p}	403.22^{q}	399.67^{q}	372.26^{k}
200	313.89^{j}	386.18^{p}	407.04^{qr}	425.67^{rs}	429.22^{s}	392.40^{l}
225	343.03^{lm}	405.41^{q}	417.00^{q}	443.75^{t}	445.07^{t}	410.85^{m}
250	358.49^{mn}	424.49^{rs}	429.50^{s}	463.75^{u}	460.66^{u}	427.38^{n}
Means^{2}	266.13^{a}	311.30^{b}	322.14^{c}	335.97^{d}	334.32^{d}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 4.53, I/P = 2.71, P.I/P 10.14] for Means ^{1,2,3} respectively.

B: LOSKOP SOILS

13. The effects of P treatments and incubation period on the dialysis membrane tubes-hydrous ferric oxide (DMT-HFO) extractable P_i (DMT-HFO-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	15009.25	1154.56	1958.95	<.01
INC/PER (I/P)	4	6628.26	1657.06	2811.56	<.01
PHOSP.INC/PER (P.I/P)	52	2963.04	56.98	96.68	<.01
REPS.	2	6.57	3.28	5.97	
Residual	140	82.51	0.59		
Total	209	24683.07			

SE = 0.78; CV = 4.8

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^3	60^3	120^3	180^3	240^3	$Means^1$
0	5.40^{ab}	5.25^{ab}	5.35^{ab}	4.92^{ab}	4.54^{a}	5.09^{a}
5	8.67^{bc}	5.79^{ab}	5.49^{ab}	5.21^{ab}	4.63^{a}	5.96^{ab}
10	9.33^{c}	5.79^{ab}	5.75^{ab}	5.50^{ab}	5.00^{ab}	6.27^{b}
20	10.00^{c}	6.46^{ab}	6.29^{ab}	6.04^{ab}	5.42^{ab}	6.84^{bc}
25	10.67^{cd}	7.50^{bc}	7.09^{b}	6.84^{b}	6.46^{ab}	7.71^{c}
50	18.56^{fg}	10.71^{cd}	7.96^{bc}	8.92^{bc}	7.21^{b}	10.67^{d}
75	26.00^{i}	14.67^{ef}	14.25^{e}	12.09^{d}	10.19^{cd}	15.44^{e}
100	39.33^{m}	22.08^{h}	15.58^{ef}	14.33^{e}	11.50^{d}	19.36^{f}
125	40.22^{mn}	25.33^{i}	17.08^{fg}	15.83^{ef}	14.28^{e}	24.15^{g}
150	41.89^{n}	28.33^{j}	19.00^{g}	17.75^{fg}	15.57^{ef}	27.31^{h}
175	51.33^{p}	30.00^{j}	21.00^{gh}	19.20^{g}	15.92^{ef}	30.49^{i}
200	64.78^{q}	33.58^{k}	23.08^{hi}	19.58^{g}	16.75^{f}	31.95^{j}
225	67.00^{r}	36.25^{l}	23.67^{hi}	20.58^{gh}	17.00^{fg}	32.90^{k}
250	68.11^{r}	38.08^{lm}	25.17^{i}	21.08^{gh}	17.25^{fg}	33.94^{l}
$Means^2$	32.95^{e}	19.27^{d}	14.05^{c}	12.78^{b}	10.84^{a}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 0.94, I/P = 0.56, P.I/P = 2.11] for Means ^{1,2,3} respectively.

14. The effects of P treatments and incubation period on the 0.5M $NaHCO_3$ extractable inorganic P ($-HCO_3-P_i$) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	32533.20	2502.55	3717.02	<.01
INC/PER (I/P)	4	10240.51	2560.13	3802.54	<.01
PHOSP.INC/PER (P.I/P)	52	3037.63	58.41	86.76	<.01
REPS.	2	5.46	2.73	4.25	
Residual	140	94.26	0.67		
Total	209	45905.60			

SE = 0.82; CV = 3.9

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	$Means^{1}$
0	12.83^{d}	8.11^{bc}	6.89^{ab}	6.00^{ab}	5.56^{ab}	7.88^{a}
5	13.23^{de}	8.55^{bc}	7.00^{ab}	6.33^{ab}	5.11^{a}	8.04^{ab}
10	13.44^{de}	9.00^{bc}	7.22^{ab}	6.92^{ab}	5.56^{ab}	8.43^{ab}
20	13.84^{de}	9.83^{c}	7.42^{b}	7.17^{ab}	6.44^{ab}	8.94^{b}
25	17.76^{f}	10.92^{cd}	9.67^{bc}	7.62^{bc}	6.89^{ab}	10.57^{c}
50	30.08^{i}	15.42^{e}	13.42^{de}	8.13^{bc}	7.67^{bc}	14.94^{d}
75	38.02^{k}	16.25^{ef}	14.58^{de}	10.63^{cd}	9.50^{bc}	17.80^{e}
100	45.12^{m}	28.83^{i}	25.21^{h}	16.00^{ef}	13.17^{de}	25.67^{f}
125	52.38^{p}	37.22^{k}	30.42^{i}	19.63^{fg}	14.33^{de}	30.80^{g}
150	59.29^{q}	40.28^{l}	33.46^{j}	22.00^{gh}	18.83^{fg}	34.77^{h}
175	61.84^{r}	46.00^{m}	37.58^{k}	23.17^{h}	20.17^{g}	37.75^{i}
200	74.95^{s}	49.03^{n}	41.75^{l}	28.92^{i}	23.17^{h}	43.56^{j}
225	82.76^{t}	51.25^{np}	45.83^{m}	39.25^{kl}	37.67^{k}	51.35^{k}
250	84.42^{t}	51.25^{np}	46.80^{mn}	41.38^{l}	37.92^{k}	52.35^{k}
$Means^{2}$	42.85^{e}	27.28^{d}	23.38^{c}	17.37^{b}	15.14^{a}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.01, I/P = 0.60, P.I/P = 2.25] for Means ^{1,2,3} respectively.

15. The effects of P treatments and incubation period on the 0.5M $NaHCO_3$ extractable organic P ($-HCO_3-P_o$) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1916.26	147.40	170.68	<.01
INC/PER (I/P)	4	577.15	144.29	167.07	<.01
PHOSP.INC/PER (P.I/P)	52	255.99	4.92	5.70	<.01
REPS.	2	0.18	0.092	0.11	
Residual	140	120.91	0.86		
Total	209	2870.31			

SE = 0.93; CV = 7.0

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1[3]	60[3]	120[3]	180[3]	240[3]	Means[1]
0	9.55^{ab}	10.00^{ab}	10.25^{ab}	8.50^{ab}	7.83^{a}	9.23^{a}
5	9.63^{ab}	10.75^{b}	11.08^{bc}	8.25^{ab}	8.08^{ab}	9.56^{ab}
10	10.05^{ab}	10.79^{b}	12.39^{bc}	8.59^{ab}	8.25^{ab}	10.01^{ab}
20	10.28^{ab}	10.75^{b}	12.17^{bc}	9.21^{ab}	8.83^{ab}	10.25^{ab}
25	10.28^{ab}	11.42^{bc}	12.48^{bc}	10.21^{ab}	8.83^{ab}	10.65^{b}
50	10.54^{b}	12.88^{bc}	13.55^{c}	11.75^{bc}	10.92^{b}	11.33^{b}
75	10.98^{b}	15.58^{cd}	14.21^{cd}	13.79^{cd}	11.50^{bc}	13.21^{c}
100	11.33^{bc}	16.08^{cd}	16.25^{d}	13.79^{cd}	12.25^{bc}	13.94^{cd}
125	11.32^{bc}	16.33^{de}	17.50^{de}	14.63^{cd}	13.63^{c}	14.68^{d}
150	11.35^{bc}	17.30^{de}	17.92^{de}	15.09^{cd}	14.00^{cd}	15.13^{d}
175	11.58^{bc}	17.38^{de}	18.17^{de}	15.88^{cd}	15.58^{cd}	15.72^{de}
200	12.18^{bc}	20.30^{ef}	18.84^{e}	15.88^{cd}	15.67^{cd}	16.57^{e}
225	13.70^{cd}	20.38^{ef}	18.96^{e}	17.92^{de}	16.08^{cd}	17.41^{ef}
250	14.12^{cd}	22.75^{f}	19.37^{e}	18.42^{de}	16.41^{de}	18.21^{f}
Means[2]	10.99^{a}	15.19^{d}	15.23^{d}	12.99^{c}	11.99^{b}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.14, I/P = 0.68, P.I/P = 2.55] for Means [1,2,3] respectively.

16. The effects of added P and incubation period on the 0.1M NaOH-extractable inorganic P (-OH-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	67318.85	5178.37	3021.60	<.01
INC/PER (I/P)	4	32566.07	8141.52	4750.60	<.01
PHOSP.INC/PER (P.I/P)	52	8692.11	167.16	97.54	<.01
REPS.	2	4.55	2.27	1.33	
Residual	140	239.93	1.71		
Total	209	108816.96			

SE = 1.31; CV = 2.4

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	21.43^{a}	26.42^{b}	31.17^{c}	34.92^{d}	37.83^{de}	30.35^{a}
5	23.83^{ab}	26.67^{b}	31.67^{cd}	34.97^{d}	37.97^{de}	31.02^{a}
10	23.80^{ab}	26.83^{b}	35.83^{d}	35.00^{d}	38.17^{de}	31.93^{a}
20	25.80^{b}	28.75^{bc}	36.50^{de}	36.00^{de}	42.83^{ef}	33.98^{b}
25	27.10^{b}	32.17^{cd}	37.50^{de}	40.17^{e}	45.33^{f}	36.45^{c}
50	39.43^{e}	46.33^{fg}	54.33^{h}	61.50^{ij}	65.50^{jk}	53.42^{d}
75	41.77^{ef}	49.00^{g}	60.50^{i}	68.42^{k}	70.00^{kl}	57.94^{e}
100	45.57^{fg}	52.83^{h}	62.17^{ij}	72.58^{l}	78.58^{mn}	62.35^{f}
125	50.73^{gh}	64.50^{j}	72.17^{l}	77.00^{mn}	83.33^{np}	69.55^{g}
150	54.80^{h}	65.83^{jk}	73.33^{lm}	83.17^{np}	87.83^{pq}	72.99^{h}
175	60.97^{ij}	66.33^{jk}	76.33^{m}	86.33^{pq}	90.07^{q}	76.01^{i}
200	62.23^{ij}	73.25^{lm}	84.67^{p}	89.50^{q}	96.07^{rs}	81.14^{j}
225	68.00^{jk}	80.33^{n}	85.83^{p}	93.97^{r}	98.67^{s}	85.36^{k}
250	70.30^{kl}	81.08^{np}	86.83^{pq}	96.75^{rs}	103.90^{t}	87.77^{l}
Means^{2}	43.98^{a}	51.45^{b}	59.20^{c}	65.02^{d}	66.72^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.60, I/P = 0.96, P.I/P = 3.59] for Means ^{1,2,3} respectively.

17. The effects of P treatments and incubation period on the 0.1M NaOH extractable organic P (-OH-P_o) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	3007.22	231.32	406.11	<.01
INC/PER (I/P)	4	2445.34	611.33	1073.25	<.01
PHOSP.INC/PER (P.I/P)	52	993.62	19.11	33.55	<.01
REPS.	2	0.20	0.10	0.17	
Residual	140	79.74	0.57		
Total	209	6525.92			

SE = 0.75; CV = 5.0

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	7.38^{a}	9.81^{b}	10.17^{bc}	11.38^{bc}	11.58^{bc}	10.06^{ab}
5	7.55^{ab}	9.88^{b}	11.08^{bc}	10.83^{bc}	9.83^{b}	9.83^{a}
10	7.70^{ab}	9.88^{b}	11.50^{bc}	11.25^{bc}	10.79^{bc}	10.22^{ab}
20	8.70^{ab}	10.29^{bc}	13.00^{cd}	11.25^{bc}	10.92^{bc}	10.83^{b}
25	8.48^{ab}	11.96^{c}	13.50^{cd}	13.57^{cd}	13.18^{cd}	12.14^{c}
50	8.85^{ab}	13.00^{cd}	14.71^{de}	14.86^{de}	14.50^{d}	13.18^{d}
75	9.58^{b}	13.42^{cd}	14.79^{de}	15.25^{de}	15.13^{de}	13.63^{d}
100	10.12^{bc}	13.71^{cd}	16.42^{de}	17.40^{ef}	16.13^{de}	14.76^{e}
125	10.20^{bc}	14.75^{de}	16.67^{e}	18.08^{ef}	16.92^{ef}	15.32^{ef}
150	10.30^{bc}	15.71^{de}	18.33^{ef}	18.92^{f}	17.13^{ef}	16.08^{f}
175	10.15^{bc}	16.09^{de}	18.46^{ef}	19.33^{f}	18.97^{f}	16.60^{fg}
200	10.35^{bc}	16.13^{de}	19.83^{fg}	20.67^{fg}	20.09^{f}	17.21^{g}
225	10.97^{bc}	17.34^{ef}	22.75^{gh}	23.04^{gh}	21.79^{g}	19.18^{h}
250	11.32^{bc}	18.13^{ef}	23.92^{h}	23.88^{h}	22.77^{g}	20.00^{h}
Means^{2}	9.40^{a}	13.58^{b}	16.08^{c}	16.41^{d}	15.62^{c}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD [P = 0.93, I/P = 0.55, P.I/P = 2.07] for Means ^{1,2,3} respectively.

18. The effects of P treatments and incubation period on the 1M HCl extractable Ca - bound P_i (D/HCl-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1385.63	106.59	252.64	<.01
INC/PER (I/P)	4	457.51	114.38	271.11	<.01
PHOSP.INC/PER (P.I/P)	52	141.62	2.72	6.46	<.01
REPS.	2	0.96	0.48	1.14	
Residual	140	59.06	0.42		
Total	209	2043.83			

SE = 0.65; CV = 6.0

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	5.97^{a}	5.99^{a}	6.17^{ab}	6.25^{ab}	6.08^{ab}	6.09^{a}
5	6.23^{ab}	6.79^{ab}	7.50^{ab}	8.33^{bc}	7.83^{b}	7.34^{b}
10	6.47^{ab}	6.96^{ab}	9.25^{bc}	9.21^{bc}	8.50^{bc}	8.08^{bc}
20	7.30^{ab}	7.04^{ab}	9.17^{bc}	9.67^{c}	8.83^{bc}	8.60^{c}
25	7.50^{ab}	8.95^{bc}	9.43^{bc}	10.15^{cd}	11.33^{cd}	9.48^{d}
50	8.00^{bc}	9.13^{bc}	10.22^{cd}	11.18^{cd}	11.67^{d}	10.04^{de}
75	8.93^{bc}	9.67^{c}	11.21^{cd}	11.38^{cd}	11.79^{d}	10.60^{e}
100	9.28^{bc}	10.14^{cd}	11.70^{d}	12.06^{d}	12.92^{de}	11.22^{ef}
125	9.40^{bc}	10.79^{cd}	11.80^{d}	14.29^{e}	12.81^{de}	11.62^{f}
150	9.93^{cd}	10.63^{cd}	12.13^{d}	14.58^{e}	16.07^{ef}	12.67^{g}
175	10.02^{cd}	10.75^{cd}	12.75^{de}	15.00^{ef}	16.75^{f}	13.06^{gh}
200	10.43^{cd}	12.96^{d}	13.25^{de}	14.67^{ef}	16.42^{f}	13.55^{h}
225	10.73^{cd}	12.64^{de}	14.73^{ef}	15.46^{ef}	16.63^{f}	14.03^{h}
250	11.97^{d}	12.83^{de}	15.75^{ef}	16.88^{f}	17.50^{f}	14.99^{i}
Means^{2}	8.73^{a}	9.66^{b}	11.15^{c}	12.08^{d}	12.51^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 0.80, I/P = 0.48, P.I/P = 1.78] for Means ^{1,2,3} respectively.

19. The effects of added P and incubation period on the conc. HCl digestible inorganic P) (C/HCl-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	19898.28	1530.64	637.69	<.01
INC/PER (I/P)	4	9436.47	2359.12	982.85	<.01
PHOSP.INC/PER (P.I/P)	52	5076.66	97.63	40.67	<.01
REPS.	2	25.91	12.95	5.76	
Residual	140	336.04	2.40		
Total	209	34747.45			

SE = 1.55; CV = 3.3

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	29.33^{a}	31.50^{ab}	31.92^{ab}	32.33^{ab}	34.83^{bc}	31.98^{a}
5	31.73^{ab}	31.67^{ab}	33.83^{b}	33.08^{ab}	35.50^{bc}	33.16^{a}
10	32.27^{ab}	32.42^{ab}	34.67^{bc}	33.58^{ab}	35.83^{bc}	33.75^{ab}
20	32.27^{ab}	32.42^{ab}	35.50^{bc}	33.83^{b}	42.17^{cd}	35.24^{b}
25	32.27^{ab}	33.00^{ab}	38.58^{cd}	40.42^{cd}	42.42^{cd}	37.34^{c}
50	35.30^{bc}	35.08^{bc}	43.50^{de}	43.17^{d}	52.67^{f}	41.94^{d}
75	36.67^{bc}	40.08^{c}	45.42^{de}	52.58^{f}	54.67^{fg}	45.88^{e}
100	37.67^{bc}	41.58^{c}	47.75^{e}	53.67^{fg}	55.08^{fg}	47.15^{e}
125	38.20^{c}	42.17^{c}	52.67^{f}	53.17^{fg}	60.83^{gh}	49.41^{f}
150	38.53^{cd}	42.17^{c}	55.25^{fg}	60.25^{gh}	64.33^{h}	52.11^{g}
175	38.93^{cd}	43.92^{de}	58.83^{g}	61.33^{gh}	69.42^{i}	54.49^{h}
200	39.87^{cd}	48.42^{ef}	60.58^{gh}	65.63^{hi}	71.08^{i}	57.12^{i}
225	40.67^{cd}	57.25^{g}	67.17^{hi}	68.58^{hi}	76.42^{j}	62.02^{j}
250	42.60^{d}	60.25^{gh}	67.33^{hi}	75.50^{j}	87.92^{k}	66.72^{k}
Means^{2}	36.17^{a}	40.85^{c}	48.07^{b}	50.51^{d}	55.94^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.90, I/P = 1.14, P.I/P = 4.25] for Means ^{1,2,3} respectively.

20. The effects of P treatments and incubation period on the conc. HCl digestible organic P (C/HCl-P_o) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1644.55	126.50	166.51	<.01
INC/PER (I/P)	4	1063.39	265.85	349.91	<.01
PHOSP.INC/PER (P.I/P)	52	444.04	8.54	11.24	<.01
REPS.	2	0.74	0.37	0.48	
Residual	140	106.37	0.76		
Total	209	3258.35			

SE = 0.87; CV = 6.5

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	9.20^{ab}	8.78^{a}	9.94^{ab}	9.28^{ab}	9.39^{ab}	9.32^{a}
5	9.02^{ab}	8.89^{ab}	10.97^{ab}	9.69^{ab}	8.95^{a}	9.50^{ab}
10	9.11^{ab}	9.06^{ab}	10.72^{ab}	9.72^{ab}	10.62^{ab}	9.85^{ab}
20	9.33^{ab}	9.72^{ab}	11.00^{ab}	10.11^{ab}	12.33^{b}	10.50^{b}
25	9.96^{ab}	10.11^{ab}	11.25^{b}	11.89^{bc}	13.39^{b}	11.32^{bc}
50	10.00^{ab}	10.78^{ab}	11.78^{bc}	13.11^{bc}	15.94^{cd}	12.32^{c}
75	10.00^{ab}	11.00^{ab}	11.83^{bc}	13.39^{bc}	17.50^{d}	12.74^{c}
100	10.18^{ab}	11.61^{bc}	13.72^{c}	14.22^{cd}	20.05^{e}	13.96^{d}
125	10.44^{ab}	14.11^{cd}	13.78^{c}	15.27^{cd}	20.89^{ef}	14.90^{de}
150	10.71^{ab}	14.50^{cd}	14.06^{cd}	15.38^{cd}	21.22^{ef}	15.17^{e}
175	10.67^{ab}	14.72^{cd}	15.05^{cd}	16.63^{d}	22.28^{ef}	15.87^{ef}
200	11.78^{bc}	15.05^{cd}	15.89^{cd}	16.89^{d}	22.28^{ef}	16.38^{f}
225	12.69^{bc}	16.44^{d}	16.78^{d}	17.72^{de}	22.83^{f}	17.29^{f}
250	12.40^{bc}	15.83^{d}	17.17^{d}	17.42^{d}	23.17^{f}	17.20^{f}
Means^{2}	10.39^{a}	12.19^{b}	13.14^{c}	13.62^{c}	17.20^{d}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.07, I/P = 0.64, P.I/P = 2.39] for Means ^{1,2,3} respectively.

21. The effects of added P and incubation periods on the conc.H_2SO_4 and H_2O_2 digestible P (H_2SO_4-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	22126.70	1702.05	464.53	<.01
INC/PER (I/P)	4	9565.23	2391.31	652.64	<.01
PHOSP.INC/PER (P.I/P)	52	5480.19	105.39	28.76	<.01
REPS.	2	5.11	2.55	0.69	
Residual	140	512.97	3.66		
Total	209	37685.08			

SE = 1.91; CV = 3.6

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	$Means^{1}$
0	39.83^{a}	40.67^{ab}	41.38^{ab}	41.97^{ab}	42.59^{ab}	41.29^{a}
5	39.87^{a}	41.00^{ab}	41.25^{ab}	42.01^{ab}	43.16^{ab}	41.46^{a}
10	39.93^{ab}	40.68^{ab}	41.36^{ab}	42.13^{ab}	43.33^{ab}	41.49^{a}
20	40.00^{ab}	40.92^{ab}	41.58^{ab}	42.29^{ab}	44.42^{ab}	41.84^{a}
25	40.00^{ab}	41.76^{ab}	41.80^{ab}	42.36^{ab}	44.27^{ab}	42.04^{a}
50	40.50^{ab}	41.92^{ab}	45.13^{b}	46.13^{bc}	54.78^{cd}	45.69^{b}
75	40.83^{ab}	51.13^{c}	49.95^{bc}	46.68^{bc}	58.93^{de}	49.50^{c}
100	41.00^{ab}	52.03^{c}	52.25^{cd}	57.59^{d}	60.16^{de}	52.61^{d}
125	42.17^{ab}	53.07^{cd}	54.77^{cd}	60.36^{de}	69.04^{ef}	55.88^{e}
150	42.50^{ab}	57.35^{d}	59.69^{de}	61.15^{de}	71.40^{f}	58.42^{f}
175	43.00^{ab}	63.90^{e}	66.49^{ef}	61.45^{de}	79.03^{g}	62.77^{g}
200	45.67^{b}	66.17^{ef}	70.48^{f}	71.45^{f}	79.82^{g}	66.72^{h}
225	45.67^{b}	66.71^{ef}	70.86^{f}	79.61^{g}	86.59^{h}	69.89^{i}
250	48.33^{bc}	66.90^{ef}	71.85^{f}	79.82^{g}	89.40^{h}	70.06^{i}
$Means^{2}$	42.09^{a}	51.37^{b}	53.49^{c}	55.36^{d}	61.49^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 2.35, I/P = 1.40, P.I/P = 5.25] for Means ^{1,2,3} respectively.

22. The effects of P treatments and incubation period on the total inorganic P (HFO-Pi + HCO_3-P_i + OH-P_i + conc.HCl-P_i + conc.H_2SO_4-P_i) (TOT-P_i) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.(m.v.)	s.s.	m.s.	F	F pr.
PHOSP (P)	13	771096.22	59315.09	7124.82	<.01
INC/PER (I/P)	4	45583.95	11395.99	1368.86	<.01
PHOSP.INC/PER (P.I/P)	52	16789.68	322.88	38.78	<.01
REPS.	2	120.90	60.45	7.97	
Residual	138(2)	1148.87	8.32		
Total	207(2)	829352.68			

SE = 2.88; CV = 1.4

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^3	60^3	120^3	180^3	240^3	Means^1
0	116.82^a	117.93^{ab}	122.87^b	123.40^{ab}	124.44^{ab}	121.09^a
5	123.37^{ab}	121.47^{ab}	126.75^{bc}	128.63^{bc}	130.90^{bc}	126.22^b
10	125.64^b	124.69^{ab}	134.08^d	131.35^{bc}	136.99^c	130.55^c
20	131.41^{bc}	129.43^{bc}	141.46^e	135.41^c	152.11^d	137.96^d
25	138.29^{cd}	137.30^c	145.62^e	152.56^d	163.70^{ef}	147.49^e
50	151.78^d	160.59^e	169.56^h	180.01^g	196.50^h	171.69^f
75	172.22^{fg}	180.80^g	195.92^k	197.77^h	209.08^i	191.16^g
100	184.97^g	203.51^{hi}	217.66^n	230.24^{kl}	246.41^m	216.56^h
125	203.10^{hi}	216.08^{ij}	233.90^{qr}	240.28^{lm}	254.63^n	229.60^i
150	217.95^j	229.93^k	237.86^r	246.90^{mn}	271.64^{pq}	240.86^j
175	221.09^j	254.11^{mn}	250.91^{tu}	261.49^{np}	287.35^{rs}	254.99^k
200	229.93^k	265.41^p	273.82^w	282.75^r	294.07^s	269.20^l
225	242.82^{lm}	284.42^r	285.08^x	297.40^s	322.96^u	286.54^m
250	249.73^{mn}	290.40^{rs}	293.74^{yz}	311.40^t	337.89^v	296.63^n
Means^2	179.22^a	194.00^b	202.09^c	208.54^d	223.48^e	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 3.54, I/P = 2.12, P.I/P = 7.92] for Means ^{1,2,3} respectively.

23. The effects of P treatments and incubation period on the total organic P (HCO_3-P_o + OH-P_o + conc. HCl-P_o) (TOT-P_o) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	13	18910.03	1454.62	696.21	<.01
INC/PER (I/P)	4	7809.18	1952.29	934.41	<.01
PHOSP.INC/PER (P.I/P)	52	3106.74	59.74	28.60	<.01
REPS.	2	0.25	0.13	0.06	
Residual	140	292.51	2.09		
Total	209	30118.46			

SE = 1.45; CV = 3.4

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIODS (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	26.13^{a}	28.59^{ab}	30.36^{b}	29.16^{ab}	28.80^{ab}	28.61^{a}
5	26.21^{a}	29.52^{ab}	33.14^{bc}	29.78^{ab}	28.86^{ab}	29.50^{a}
10	26.86^{ab}	29.72^{ab}	34.62^{c}	29.56^{ab}	29.66^{ab}	30.09^{a}
20	28.31^{ab}	30.77^{bc}	36.17^{cd}	30.57^{b}	36.09^{cd}	32.38^{b}
25	28.72^{ab}	33.49^{bc}	37.23^{cd}	36.67^{cd}	37.41^{cd}	34.70^{c}
50	29.39^{ab}	36.65^{cd}	40.03^{d}	40.73^{de}	45.36^{ef}	38.43^{d}
75	30.48^{b}	40.01^{d}	40.83^{de}	44.43^{e}	49.13^{f}	40.98^{e}
100	31.63^{bc}	41.41^{de}	46.39^{ef}	47.41^{ef}	52.43^{fg}	43.85^{f}
125	31.56^{bc}	45.19^{ef}	47.95^{ef}	49.38^{f}	55.44^{g}	45.90^{g}
150	32.06^{bc}	47.51^{ef}	49.31^{f}	50.39^{f}	57.35^{gh}	47.33^{gh}
175	32.40^{bc}	48.19^{ef}	51.68^{fg}	51.55^{fg}	59.83^{h}	48.73^{h}
200	34.31^{bc}	51.48^{fg}	54.55^{g}	56.44^{gh}	64.03^{i}	52.16^{i}
225	37.35^{cd}	54.15^{fg}	58.49^{gh}	62.68^{hi}	66.71^{ij}	55.88^{j}
250	37.84^{cd}	56.71^{fg}	60.45^{hi}	63.72^{hi}	70.34^{j}	57.81^{k}
Means^{2}	30.95^{a}	40.96^{b}	44.37^{c}	44.46^{c}	48.67^{d}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 1.77, I/P = 1.06, P.I/P = 3.97] for Means ^{1,2,3} respectively.

24. The effects of P treatments and incubation period on the total soil P (Total P_i + Total P_o) (TOT-P) of Loskop soil

(i). Analysis of variance

Source of variation	d.f.(m.v.)	s.s.	m.s.	F	F pr.
PHOSP (P)	13	1.03E+06	7.91E+04	8023.78	<.01
INC/PER (I/P)	4	8.83E+04	2.21E+04	2239.38	<.01
PHOSP.INC/PER (P.I/P)	52	3.25E+04	6.25E+02	63.39	<.01
REPS.	2	1.46E+02	7.28E+01	8.14	
Residual	139(1)	1.37E+03	9.85E+00		
Total	208(1)	1.15E+06			

SE = 3.14; CV = 1.3

(ii). Table of means

PHOSPH LEVELS (mg kg^{-1})	INCUBATION PERIOD (DAYS)					
	1^{3}	60^{3}	120^{3}	180^{3}	240^{3}	Means^{1}
0	142.95^{a}	146.52^{ab}	153.23^{b}	152.55^{b}	153.24^{b}	149.70^{a}
5	149.57^{ab}	150.99^{ab}	159.88^{bc}	157.41^{bc}	157.77^{bc}	155.13^{b}
10	152.50^{b}	154.41^{b}	168.70^{c}	160.91^{bc}	166.65^{c}	160.63^{c}
20	159.72^{bc}	160.19^{b}	177.63^{d}	165.98^{c}	188.20^{e}	170.34^{d}
25	167.01^{c}	170.79^{cd}	182.85^{de}	189.23^{ef}	201.10^{fg}	182.20^{e}
50	178.17^{d}	197.24^{f}	209.59^{g}	220.74^{h}	241.86^{ij}	209.52^{f}
75	202.70^{fg}	220.81^{h}	236.75^{ij}	242.20^{ij}	258.20^{k}	232.13^{g}
100	216.60^{gh}	244.92^{j}	264.05^{k}	277.65^{l}	298.84^{n}	260.41^{h}
125	234.66^{i}	261.27^{k}	281.85^{lm}	289.66^{mn}	310.07^{p}	275.50^{i}
150	253.08^{jk}	277.45^{l}	287.17^{m}	297.29^{n}	328.99^{q}	288.80^{j}
175	253.49^{jk}	298.09^{n}	298.66^{n}	313.04^{p}	347.18^{rs}	302.09^{k}
200	264.24^{k}	316.90^{p}	328.37^{q}	339.19^{r}	358.11^{s}	321.36^{l}
225	280.18^{lm}	338.57^{r}	343.57^{r}	360.09^{s}	389.67^{u}	342.42^{m}
250	287.57^{m}	347.11^{rs}	354.19^{s}	375.12^{t}	408.23^{v}	354.44^{n}
Means^{2}	210.17^{a}	234.66^{b}	246.18^{c}	252.93^{d}	272.01^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P = 3.85, I/P = 2.30, P.I/P = 8.62] for Means ^{1,2,3} respectively.

25. An example of Genstat 5 Release 4.1 computer programme used in the statistical analysis of Rustenburg and Loskop soils data.

```
1   JOB 'PHOSPHORUS BINDING IN RUSTENBURG RED CLAY'
2   "ON NETWORK H:\HOME\VICTOR as XRUST.DAT; XRUST.OUT"
3   UNITS [NVALUES=210]
4                                                               FACTOR
[LEVEL=14;LABEL=!T(P0,'P6.25','P12.5','P18.75',P25,P50,P75,P100,P125
,\
5           P150,P175,P200,P225,P250)] PHOSP
6   FACTOR [LEVELS=5;LABEL=!T(DAY1,DAY60,DAY120,DAY180,DAY240)] TIME
7   FACTOR [LEVELS=3] REPS
8   OPEN 'A:XRUST.DAT';WIDTH=160;FILETYPE=INPUT;CHAN=4
9                                                        READ[CHAN=4]
BOT,PHOSP,REPS,BL,TIME,HFOPi,HCOPi,OHPi,DHClPi,CHClPi,HSOPi,\
10 HCOPt,OHPt,CHClPt,HCOPo,OHPo,CHClPo,TOTPo,TOTPi,TOTP
    Identifier   Minimum       Mean    Maximum     Values   Missing
           BOT       1.0      105.5      210.0        210         0
            BL     1.000      9.257     18.000        210         0
         HFOPi      2.19      12.12      43.70        210         0
         HCOPi      2.75      16.97      58.13        210         0
          OHPi     33.00      68.31     108.00        210         0
        DHClPi      6.15      17.99      33.00        210         0
        CHClPi     27.00      74.89     108.06        210         0
         HSOPi     49.50      69.86     108.50        210         0
         HCOPt      7.00      30.33      75.60        210         0
          OHPt     46.80      90.31     143.25        210         0
        CHClPt     41.00      92.41     138.00        210         0
         HCOPo      3.75      13.36      26.50        210         0
          OHPo      6.50      21.99      40.38        210         0
        CHClPo     10.00      17.52      31.00        210         0
         TOTPo     22.96      52.88      87.88        210         0
         TOTPi     155.5      260.1      393.7        210         0
          TOTP     188.3      313.0      468.0        210         0
    Identifier    Values    Missing     Levels
         PHOSP       210          0         14
          REPS       210          0          3
          TIME       210          0          5
11  BLOCK REPS.PHOSP.TIME
12  TREAT PHOSP*TIME
13  FOR Y=HFOPi,HCOPi,OHPi,DHClPi,CHClPi,HSOPi,OHPt,CHClPt,\
14        HCOPt,HCOPo,OHPo,CHClPo,TOTPo,TOTPi,TOTP
15                                                              ANOVA
[PRINT=AOVTABLE,INFO,MEANS,%CV;FPROB=YES;PSE=LSD,MEAN;LSDLEVEL=0.1]
Y;\
16  RESIDUALS=RES;FITTEDVALUES=FIT
17  AKEEP TERMS=PHOSP.TIME;VARIANCE=V1
18  CALC ST_RES=RES/(SQRT(VAR(RES)))
19  GRAPH [NROWS=10;NCOL=25] ST_RES;FIT
20  HIST ST_RES
21  PRINT 'TEST FOR NORMALITY'
22  NORMTEST [PRINT=m,s,c] ST_RES
23  PRINT 'TEST HOMOGENEITY'
24  VHOMOGENITY [GROUPS=PHOSP] Y
25  VHOMOGENITY [GROUPS=TIME] Y
26  PRINT BOT,PHOSP,REPS,TIME,Y,FIT,ST_RES;DECI=4(0),2(3),4;FIELD=11
27  ENDFOR
```

APPENDICES II

A: RUSTENBURG SOIL

1. The effects of DMT-HFO extractions on the extractable solution P of Rustenburg soil as influenced by the added P, and the incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	50165.28	12541.32	9489.41	<.01
INC/PER (I/P)	2	11301.64	5650.82	4275.70	<.01
EX/TIME (E/T)	4	21064.26	5266.07	3984.57	<.01
PHOSP.INC/PER (P.I/P)	8	5822.84	727.86	550.73	<.01
PHOSP.EX/TIME (P.E/T)	16	5378.68	336.17	254.36	<.01
INCPER.EX/TIME (I.E/T)	8	472.62	59.08	44.70	<.01
PHOSP.INC/PER.EX/TIME	32	493.72	15.43	11.67	<.01
REPS	2	3.602	1.801	1.37	
Residual	150	198.24	1.32		
Total	224	94897.29			

SE = 1.15; CV = 4.7

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	3.22^{ab}	3.25^{ab}	2.85^{a}	3.11^{a}
	7	6.24^{b}	5.05^{ab}	4.50^{ab}	5.26^{b}
	14	7.77^{bc}	6.33^{b}	5.53^{ab}	6.54^{b}
	28	10.70^{cd}	7.15^{bc}	6.87^{bc}	8.24^{c}
	56	12.18^{cd}	10.42^{c}	8.92^{bc}	9.81^{cd}
Means[1]		8.01^{b}	6.04^{a}	5.73^{a}	
25	1	7.50^{bc}	3.52^{ab}	4.30^{ab}	5.11^{b}
	7	11.93^{cd}	7.17^{bc}	5.70^{ab}	8.27^{c}
	14	13.97^{d}	12.28^{cd}	7.25^{bc}	11.17^{d}
	28	24.47^{g}	17.33^{e}	9.70^{c}	17.17^{f}
	56	28.50^{h}	23.52^{fg}	12.40^{cd}	21.47^{g}
Means[1]		17.27^{d}	12.76^{c}	7.87^{b}	
50	1	17.92^{ef}	6.97^{bc}	5.27^{ab}	10.05^{cd}
	7	21.00^{f}	12.83^{cd}	10.92^{cd}	14.92^{e}
	14	26.73^{gh}	21.12^{f}	15.25^{de}	21.03^{g}
	28	31.77^{i}	25.78^{gh}	20.93^{f}	26.16^{h}
	56	38.75^{j}	34.47^{ij}	25.60^{gh}	32.94^{i}
Means[1]		27.23^{f}	20.23^{e}	15.59^{d}	

100	1	26.57^{gh}	11.38^{cd}	8.17^{bc}	15.37^{e}
	7	35.72^{j}	21.52^{fg}	15.00^{de}	24.08^{h}
	14	45.18^{kl}	32.53^{i}	19.85^{ef}	32.52^{i}
	28	52.68^{m}	42.25^{kl}	27.47^{gh}	40.80^{j}
	56	65.00^{p}	52.83^{m}	36.13^{j}	51.32^{k}
Means^{1}		45.03^{h}	32.10^{g}	21.32^{e}	
200	1	46.18^{l}	21.63^{fg}	14.62^{de}	27.48^{h}
	7	61.50^{n}	36.38^{j}	23.13^{fg}	40.34^{j}
	14	72.85^{q}	45.30^{l}	31.50^{hi}	49.88^{k}
	28	81.23^{r}	60.02^{n}	42.08^{k}	61.11^{l}
	56	96.77^{s}	74.73^{q}	53.63^{m}	75.04^{m}
Means^{1}		71.71^{j}	47.61^{i}	32.99^{g}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.41, P.I/P.E/T = 3.15, P.E/T = 1.82] for Means^{1,2,3} respectively

2. The effects of DMT-HFO extractions on the bicarbonate extracted inorganic (-HCO_3-P_i) of Rustenburg soil as influenced by the added P, and the incubation period

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	15679.07	3919.77	5893.11	<.01
INC/PER (I/P)	2	13316.45	6658.22	1.0E+04	<.01
EX/TIME (E/T)	4	1955.77	488.94	735.09	<.01
PHOSP.INC/PER (P.I/P)	8	7903.72	987.97	1485.34	<.01
PHOSP.EX/TIME (P.E/T)	16	836.51	52.28	78.60	<.01
INCPER.EX/TIME (I.E/T)	8	707.47	88.43	132.96	<.01
PHOSP.INC/PER.EX/TIME	32	268.61	8.39	12.62	<.01
REPS	2	0.33	0.16	0.24	
Residual	150	99.77	0.67		
Total	224	40767.36			

SE = 0.82; CV = 6.3

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^2	120^2	240^2	$Means^3$
0	1	7.00^{cd}	3.97^{ab}	2.80^{ab}	4.59^{bc}
	7	6.50^{bc}	3.27^{ab}	2.77^{ab}	4.18^{b}
	14	5.30^{bc}	3.07^{ab}	2.72^{ab}	3.70^{ab}
	28	4.30^{b}	2.93^{ab}	2.67^{ab}	3.30^{ab}
	56	2.77^{ab}	2.60^{ab}	1.87^{a}	2.41^{a}
$Means^1$		5.17^{c}	3.17^{ab}	2.57^{a}	
25	1	14.77^{fg}	6.22^{bc}	5.27^{bc}	8.75^{e}
	7	11.47^{e}	4.47^{bc}	4.33^{bc}	6.76^{cd}
	14	9.83^{de}	4.10^{ab}	3.33^{ab}	5.75^{c}
	28	5.10^{bc}	3.20^{ab}	3.00^{ab}	3.77^{b}
	56	3.65^{ab}	2.93^{ab}	2.30^{ab}	2.96^{ab}
$Means^1$		8.96^{e}	4.18^{b}	3.65^{b}	
50	1	20.80^{hi}	9.50^{de}	7.97^{cd}	12.76^{g}
	7	18.83^{h}	7.60^{cd}	7.00^{cd}	11.14^{f}
	14	12.63^{ef}	6.10^{bc}	6.55^{c}	8.43^{de}
	28	11.60^{ef}	5.20^{bc}	5.50^{bc}	7.43^{d}
	56	8.80^{d}	5.33^{bc}	4.77^{bc}	6.30^{cd}
$Means^1$		14.53^{g}	6.75^{d}	6.36^{d}	
100	1	33.40^{k}	14.58^{fg}	10.73^{de}	19.57^{i}
	7	27.13^{j}	10.93^{de}	9.67^{de}	15.91^{h}
	14	22.17^{i}	10.30^{de}	8.53^{cd}	13.67^{g}
	28	16.23^{g}	8.93^{d}	7.60^{cd}	10.92^{f}
	56	12.00^{ef}	8.20^{cd}	6.80^{cd}	9.00^{e}
$Means^1$		22.19^{i}	10.59^{f}	8.67^{e}	
200	1	69.80^{p}	23.02^{i}	18.80^{h}	37.21^{p}
	7	48.27^{n}	19.77^{h}	14.33^{fg}	27.46^{n}
	14	45.17^{m}	14.97^{fg}	13.83^{f}	24.66^{m}
	28	38.00^{l}	12.20^{ef}	11.57^{e}	20.59^{l}
	56	27.33^{j}	11.27^{e}	9.13^{de}	15.91^{j}
$Means^1$		45.71^{j}	16.25^{h}	13.53^{g}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 1.00, P.I/P.E/T = 2.24, P.E/T = 1.29] for $Means^{1,2,3}$ respectively.

3. The effects of DMT-HFO extractions on the hydroxide extracted inorganic P (-OH-P_i) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	73527.43	18381.86	1.11E+04	<.01
INC/PER (I/P)	2	26171.31	13085.66	7906.32	<.01
EX/TIME (E/T)	4	21487.28	5371.82	3245.64	<.01
PHOSP.INC/PER (P.I/P)	8	384.32	48.04	29.03	<.01
PHOSP.EX/TIME (P.E/T)	16	720.72	45.05	27.22	<.01
INC/PER.EX/TIME (I/P.E/T)	8	367.74	45.97	27.77	<.01
PHOSP.INC/PER.EX/TIME	32	1401.50	43.80	26.46	<.01
REPS	2	9.69	4.85	3.01	
Residual	150	248.26	1.66		
Total	224	124308.57			

SE = 1.29; CV = 2.5

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	30.13^{ef}	44.83^{ij}	55.17^{k}	43.38^{g}
	7	22.90^{d}	35.87^{g}	36.50^{g}	31.76^{d}
	14	18.58^{c}	30.83^{f}	31.33^{fg}	26.91^{c}
	28	14.77^{bc}	25.47^{de}	26.20^{d}	22.15^{b}
	56	10.77^{a}	23.23^{d}	21.33^{cd}	18.44^{a}
Means[1]		19.43^{a}	32.05^{d}	34.11^{e}	
25	1	32.80^{fg}	57.83^{kl}	57.98^{kl}	49.54^{h}
	7	24.43^{d}	43.27^{hi}	40.35^{h}	36.02^{e}
	14	21.33^{cd}	38.10^{gh}	34.92^{g}	31.45^{d}
	28	18.30^{c}	28.80^{ef}	30.77^{f}	25.96^{c}
	56	11.80^{ab}	25.43^{de}	25.27^{de}	20.83^{b}
Means[1]		21.73^{b}	38.69^{g}	37.86^{f}	
50	1	41.70^{hi}	62.10^{lm}	65.67^{mn}	56.49^{j}
	7	27.00^{e}	47.60^{j}	46.75^{ij}	40.45^{f}
	14	23.33^{d}	43.90^{i}	42.30^{hi}	36.51^{e}
	28	21.77^{cd}	34.73^{g}	34.60^{g}	30.37^{d}
	56	14.67^{b}	31.03^{f}	30.23^{ef}	25.31^{c}
Means[1]		25.69^{c}	43.87^{h}	43.91^{h}	

100	1	56.40^{kl}	74.17^{p}	74.00^{p}	68.19^{l}
	7	42.23^{hi}	59.05^{l}	59.50^{l}	53.59^{i}
	14	34.83^{g}	50.90^{j}	55.38^{k}	47.04^{g}
	28	28.33^{ef}	43.93^{i}	50.00^{j}	40.75^{f}
	56	22.77^{d}	41.83^{hi}	43.67^{hi}	36.09^{e}
Means^{1}		36.91^{f}	53.98^{i}	56.51^{j}	
200	1	90.47^{r}	100.67^{s}	106.17^{t}	99.10^{n}
	7	65.80^{mn}	75.87^{pq}	87.97^{r}	76.55^{m}
	14	58.00^{kl}	69.10^{n}	79.25^{q}	67.45^{l}
	28	48.30^{j}	64.97^{m}	69.00^{n}	60.76^{k}
	56	42.27^{hi}	56.40^{kl}	59.27^{l}	52.65^{i}
Means^{1}		60.67^{k}	73.40^{l}	79.53^{m}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.58, P.I/P.E/T = 3.53, P.E/T = 2.04] for Means^{1,2,3} respectively.

4. Effects of DMT-HFO extractions on the dilute hydrochloric acid extracted inorganic P (D/HCl-P_i) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	5060.68	1265.17	802.95	<.01
INC/PER (I/P)	2	296.67	148.34	94.14	<.01
EX/TIME (E/T)	4	1360.30	340.07	215.83	<.01
PHOSP.INC/PER (P.I/P)	8	343.59	42.95	27.26	<.01
PHOSP.EX/TIME (P.E/T)	16	242.63	15.16	9.62	<.01
INCPER.EX/TIME (I.E/T)	8	55.30	6.91	4.39	<.01
PHOSP.INC/PER.EX/TIME	32	22.97	0.72	0.46	0.99
REPS	2	5.57	2.78	1.78	
Residual	150	236.35	1.58		
Total	224	7618.48			

SE = 1.26; CV = 10.0

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	$Means^{3}$
0	1	8.43^{b}	7.72^{ab}	9.87^{bc}	8.67^{bc}
	7	5.95^{ab}	6.13^{ab}	7.80^{ab}	6.63^{ab}
	14	5.20^{ab}	6.00^{ab}	7.08^{ab}	6.09^{a}
	28	5.10^{ab}	5.53^{ab}	6.20^{ab}	5.61^{a}
	56	5.00^{ab}	4.97^{a}	5.40^{ab}	5.12^{a}
$Means^{1}$		5.94^{a}	6.07^{a}	7.27^{ab}	
25	1	10.73^{bc}	11.92^{c}	14.17^{cd}	12.27^{cd}
	7	8.00^{ab}	9.43^{bc}	11.43^{bc}	9.62^{bc}
	14	7.75^{ab}	8.80^{bc}	9.98^{bc}	8.84^{bc}
	28	7.07^{ab}	7.92^{ab}	9.33^{bc}	8.11^{b}
	56	6.60^{ab}	6.92^{ab}	7.77^{ab}	7.10^{ab}
$Means^{1}$		8.03^{b}	9.00^{bc}	10.54^{c}	
50	1	13.53^{cd}	13.07^{cd}	18.33^{de}	14.98^{de}
	7	10.33^{bc}	12.50^{cd}	14.17^{cd}	12.33^{cd}
	14	9.40^{bc}	10.43^{bc}	12.72^{cd}	10.85^{c}
	28	9.20^{bc}	9.23^{bc}	10.30^{bc}	10.58^{c}
	56	8.57^{bc}	8.80^{bc}	8.80^{bc}	8.72^{bc}
$Means^{1}$		10.21^{c}	11.41^{cd}	12.86^{e}	
100	1	15.50^{d}	16.87^{de}	22.27^{ef}	18.21^{ef}
	7	13.80^{cd}	15.00^{cd}	16.40^{d}	15.07^{de}
	14	10.80^{bc}	14.43^{cd}	14.95^{cd}	13.39^{d}
	28	11.50^{bc}	12.53^{cd}	12.53^{cd}	12.19^{cd}
	56	10.87^{bc}	11.07^{bc}	11.67^{bc}	11.20^{c}
$Means^{1}$		12.49^{d}	13.98^{de}	15.56^{e}	
200	1	20.62^{e}	28.93^{g}	27.53^{fg}	25.69^{g}
	7	17.25^{de}	24.50^{f}	20.52^{e}	20.76^{f}
	14	14.70^{cd}	24.67^{f}	18.78^{de}	19.38^{f}
	28	14.27^{cd}	20.03^{e}	16.53^{d}	16.94^{e}
	56	13.23^{cd}	18.13^{de}	14.30^{cd}	15.22^{de}
$Means^{1}$		16.01^{e}	23.25^{g}	19.53^{f}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.54, P.I/P.E/T = 3.44, P.E/T = 1.99] for $Means^{1,2,3}$ respectively.

5. The effects of DMT-HFO extractions on the concentrated hydrochloric acid extracted inorganic P (C/HCl-P_i) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	13994.08	3498.52	2040.61	<.01
INC/PER (I/P)	2	6244.70	3122.35	1821.20	<.01
EX/TIME (E/T)	4	5914.42	1478.61	862.44	<.01
PHOSP.INC/PER (P.I/P)	8	2392.25	299.03	174.42	<.01
PHOSP.EX/TIME (P.E/T)	16	165.35	10.33	6.03	<.01
INC/PER.EX/TIME (I/P.E/T)	8	903.07	112.88	65.84	<.01
PHOSP.INC/PER.EX/TIME	32	293.83	9.18	5.36	<.01
REPS	2	2.65	1.33	0.77	
Residual	150	257.17	1.71		
Total	224	30164.87			

SE = 1.31; CV = 2.4

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	48.33^{d}	51.27^{de}	58.70^{fg}	52.77^{g}
	7	41.27^{bc}	43.33^{bc}	50.00^{d}	44.87^{d}
	14	40.53^{b}	41.77^{bc}	46.60^{cd}	42.97^{cd}
	28	38.60^{ab}	38.93^{ab}	40.60^{b}	39.38^{bc}
	56	35.77^{a}	35.83^{a}	38.27^{ab}	36.62^{a}
Means^{1}		40.90^{a}	42.23^{ab}	46.83^{c}	
25	1	50.60^{de}	52.53^{ef}	60.00^{g}	54.38^{gh}
	7	43.67^{bc}	46.27^{cd}	53.90^{ef}	47.95^{e}
	14	43.60^{bc}	43.20^{bc}	49.37^{de}	45.39^{de}
	28	40.20^{b}	41.53^{bc}	46.67^{cd}	42.80^{cd}
	56	37.07^{ab}	37.33^{ab}	42.27^{bc}	38.89^{b}
Means^{1}		44.18^{b}	46.75^{c}	53.21^{d}	
50	1	51.20^{de}	55.40^{ef}	64.40^{h}	57.00^{h}
	7	45.53^{cd}	49.00^{de}	56.07^{f}	50.20^{f}
	14	44.53^{c}	45.93^{cd}	51.33^{de}	47.26^{e}
	28	41.33^{bc}	42.87^{bc}	49.27^{de}	44.49^{d}
	56	38.33^{ab}	40.53^{b}	45.00^{cd}	41.29^{c}
Means^{1}		44.18^{b}	46.75^{c}	53.21^{d}	

100	1	52.00^{e}	61.17^{gh}	76.30^{j}	63.16^{i}
	7	48.53^{de}	54.67^{ef}	62.93^{gh}	55.38^{h}
	14	46.80^{cd}	53.40^{ef}	59.00^{fg}	53.07^{g}
	28	43.60^{bc}	47.00^{cd}	53.00^{ef}	47.87^{e}
	56	42.47^{bc}	45.87^{cd}	48.00^{cd}	45.45^{de}
Means[1]		46.68^{c}	52.42^{d}	59.85^{e}	
200	1	54.67^{ef}	76.60^{j}	95.80^{m}	75.69^{m}
	7	54.20^{ef}	73.87^{j}	86.10^{l}	71.39^{l}
	14	53.53^{ef}	71.20^{ij}	81.60^{k}	68.78^{k}
	28	52.67^{ef}	68.20^{i}	76.67^{j}	65.85^{j}
	56	49.87^{de}	65.93^{hi}	71.67^{ij}	62.49^{i}
Means[1]		52.99^{d}	71.16^{f}	82.37^{g}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.60, P.I/P.E/T = 3.59, P.E/T = 2.07] for Means[1,2,3] respectively.

6. The effects of DMT-HFO extractions on the concentrated sulphuric acid extracted residual P (H_2SO_4-P_i) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	17977.67	4494.42	2268.72	<.01
INC/PER (I/P)	2	7174.57	3587.28	1810.81	<.01
EX/TIME (E/T)	4	8076.88	2019.22	1019.28	<.01
PHOSP.INC/PER (P.I/P)	8	4797.12	599.64	302.69	<.01
PHOSP.EX/TIME (P.E/T)	16	520.13	32.52	16.41	<.01
INC/PER.EX/TIME (I/P.E/T)	8	482.38	60.30	30.44	<.01
PHOSP.INCPER.EXTIME	32	568.24	17.76	8.96	<.01
REPS	2	0.98	0.49	0.25	
Residual	150	297.16	1.98		
Total	224	39894.15			

SE = 1.41; CV = 2.4

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	56.67^{hi}	58.42^{hi}	60.83^{ij}	58.64^{h}
	7	39.33^{d}	45.67^{ef}	50.67^{fg}	45.22^{e}
	14	36.03^{cd}	40.75^{de}	48.17^{fg}	41.65^{d}
	28	30.42^{b}	33.88^{bc}	40.40^{de}	34.90^{b}
	56	26.08^{a}	31.33^{b}	35.25^{c}	30.89^{a}
Means^{1}		37.71^{a}	42.01^{b}	47.06^{d}	
25	1	59.92^{i}	60.92^{ij}	68.13^{jk}	62.99^{i}
	7	44.50^{ef}	49.75^{fg}	58.83^{hi}	51.03^{f}
	14	38.17^{cd}	45.13^{ef}	56.92^{hi}	46.74^{e}
	28	31.83^{bc}	38.02^{cd}	48.33^{fg}	39.39^{c}
	56	28.25^{ab}	33.92^{bc}	43.33^{e}	35.17^{b}
Means^{1}		40.53^{b}	45.55^{c}	55.11^{f}	
50	1	61.72^{ij}	68.67^{k}	76.25^{l}	68.88^{k}
	7	47.67^{f}	54.58^{gh}	64.67^{j}	55.64^{g}
	14	43.40^{e}	49.77^{fg}	59.42^{hi}	50.86^{f}
	28	37.67^{cd}	44.30^{ef}	52.73^{gh}	44.90^{e}
	56	31.20^{b}	36.52^{cd}	47.75^{f}	38.49^{c}
Means^{1}		44.33^{c}	50.77^{e}	60.16^{h}	
100	1	67.83^{jk}	79.08^{l}	91.00^{n}	79.30^{m}
	7	51.75^{g}	67.90^{jk}	78.33^{l}	65.99^{j}
	14	50.77^{fg}	61.45^{ij}	71.83^{k}	61.35^{i}
	28	43.25^{e}	50.98^{fg}	64.33^{j}	52.85^{f}
	56	36.50^{cd}	45.60^{ef}	58.92^{hi}	47.01^{e}
Means^{1}		50.02^{e}	61.00^{h}	75.88^{i}	
200	1	69.83^{k}	92.67^{np}	116.13^{r}	92.88^{p}
	7	59.67^{hi}	85.80^{m}	103.25^{q}	82.91^{n}
	14	55.93^{h}	77.50^{l}	96.35^{p}	76.59^{l}
	28	53.83^{gh}	70.23^{k}	88.67^{mn}	70.91^{k}
	56	46.90^{ef}	66.42^{jk}	86.00^{m}	66.44^{j}
Means^{1}		57.23^{g}	78.52^{j}	98.08^{k}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.72, P.I/P.E/T = 3.86, P.E/T = 2.23] for Means^{1,2,3} respectively.

7. The effects of DMT-HFO extractions on the bicarbonate extracted organic P ((-HCO_3-P_o) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1594.35	398.59	464.68	<.01
INC/PER (I/P)	2	369.16	184.58	215.19	<.01
EX/TIME (E/T)	4	1786.47	446.62	520.67	<.01
PHOSP.INC/PER (P.I/P)	8	136.44	17.06	19.88	<.01
PHOSP.EX/TIME (P.E/T)	16	123.68	7.73	9.01	<.01
INC/PER.EX/TIME (I/P.E/T)	8	47.90	5.99	6.98	<.01
PHOSP.INC/PER.EX/TIME	32	150.94	4.72	5.50	<.01
REPS	2	3.45	1.72	2.04	
Residual	150	128.67	0.86		
Total	224	4337.61			

SE = 0.93; CV = 9.4

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	11.50^{de}	9.03^{d}	6.90^{cd}	9.14^{e}
	7	3.50^{ab}	7.33^{cd}	5.70^{bc}	5.51^{bc}
	14	1.97^{ab}	6.50^{cd}	4.00^{bc}	4.16^{b}
	28	1.37^{ab}	5.00^{bc}	3.87^{bc}	3.41^{ab}
	56	1.13^{a}	4.28^{bc}	2.50^{ab}	2.64^{a}
Means[1]		3.89^{a}	6.43^{c}	4.59^{ab}	
25	1	11.60^{e}	10.45^{de}	9.40^{de}	10.84^{f}
	7	4.70^{bc}	8.35^{cd}	7.00^{cd}	6.68^{cd}
	14	4.40^{bc}	6.90^{cd}	5.67^{bc}	5.66^{c}
	28	3.23^{ab}	5.97^{bc}	4.43^{bc}	4.54^{bc}
	56	2.22^{ab}	4.80^{bc}	3.80^{b}	3.61^{ab}
Means[1]		5.23^{b}	7.29^{cd}	6.06^{bc}	
50	1	12.27^{ef}	12.33^{ef}	11.60^{e}	12.07^{fg}
	7	5.50^{bc}	9.97^{de}	8.88^{cd}	8.12^{de}
	14	4.20^{bc}	8.47^{cd}	6.78^{cd}	6.48^{cd}
	28	3.13^{ab}	7.63^{cd}	5.50^{bc}	5.42^{bc}
	56	2.40^{ab}	6.50^{cd}	4.40^{bc}	4.43^{bc}
Means[1]		5.50^{b}	8.98^{d}	7.43^{cd}	

100	1	12.50^{ef}	14.92^{f}	12.27^{ef}	13.23^{g}
	7	7.77^{cd}	11.57^{de}	10.33^{de}	9.89^{ef}
	14	6.50^{bc}	9.77^{de}	9.30^{de}	8.52^{de}
	28	5.17^{bc}	8.47^{cd}	7.53^{cd}	7.06^{cd}
	56	3.87^{bc}	7.63^{cd}	6.67^{cd}	6.06^{cd}
Means[1]		7.16^{c}	10.47^{e}	9.22^{d}	
200	1	13.53^{ef}	17.25^{g}	14.20^{f}	14.99^{h}
	7	9.37^{de}	14.03^{ef}	11.67^{ef}	11.69^{f}
	14	7.40^{cd}	12.47^{ef}	10.67^{de}	10.18^{e}
	28	6.40^{c}	10.13^{de}	9.50^{de}	8.68^{de}
	56	5.27^{bc}	8.73^{cd}	8.18^{cd}	7.39^{d}
Means[1]		8.39^{d}	12.52^{f}	10.84^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.001) LSD (Fisher) [P.I/P = 1.14, P.I/P.E/T = 2.54, P.E/T = 1.46] for Means[1,2,3] respectively.

8. The effects of DMT-HFO extractions on the hydroxide extracted organic P (-OH-P_o) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	3733.95	933.49	533.54	<.01
INC/PER (I/P)	2	682.17	341.09	194.95	<.01
EX/TIME (E/T)	4	1213.40	303.35	173.38	<.01
PHOSP.INC/PER (P.I/P)	8	613.06	76.63	43.80	<.01
PHOSP.EX/TIME (P.E/T)	16	45.17	2.82	1.61	0.71
INC/PER.EX/TIME (I/P.E/T)	8	175.11	21.89	12.51	<.01
PHOSP.INC/PER.EX/TIME	32	90.58	2.83	1.62	0.29
REPS	2	5.48	2.74	1.58	
Residual	150	262.44	1.75		
Total	224	6815.87			

SE = 1.32; CV = 8.0

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	12.97^{bc}	12.37^{bc}	10.75^{bc}	12.03^{cd}
	7	9.63^{ab}	10.28^{bc}	9.23^{ab}	9.71^{bc}
	14	8.55^{ab}	9.37^{ab}	8.20^{ab}	8.71^{b}
	28	7.00^{ab}	8.07^{ab}	7.92^{ab}	7.66^{ab}
	56	6.10^{a}	6.83^{ab}	6.80^{ab}	6.58^{a}
Means^{1}		8.85^{a}	9.38^{ab}	8.58^{a}	
25	1	13.17^{bc}	13.63^{c}	12.82^{bc}	13.21^{d}
	7	10.90^{bc}	12.37^{bc}	10.95^{bc}	11.41^{cd}
	14	9.33^{ab}	11.87^{bc}	10.62^{bc}	10.61^{c}
	28	8.00^{ab}	9.93^{bc}	9.77^{b}	9.23^{bc}
	56	7.53^{ab}	8.50^{ab}	8.43^{ab}	8.15^{ab}
Means^{1}		9.79^{ab}	11.26^{bc}	10.52^{b}	
50	1	14.03^{c}	14.23^{cd}	13.63^{c}	13.96^{d}
	7	11.67^{bc}	13.10^{bc}	12.75^{bc}	12.51^{cd}
	14	10.00^{bc}	12.30^{bc}	11.30^{bc}	11.20^{cd}
	28	9.53^{ab}	11.40^{bc}	10.50^{bc}	10.48^{c}
	56	9.00^{ab}	10.23^{bc}	9.57^{ab}	9.60^{bc}
Means^{1}		10.85^{bc}	12.25^{c}	11.55^{bc}	
100	1	14.80^{cd}	18.60^{d}	15.33^{cd}	16.24^{e}
	7	12.90^{bc}	15.88^{cd}	13.45^{c}	14.08^{d}
	14	11.50^{bc}	13.30^{bc}	12.15^{bc}	12.32^{cd}
	28	10.00^{bc}	13.00^{bc}	11.47^{bc}	11.49^{cd}
	56	9.50^{ab}	11.50^{bc}	10.50^{bc}	10.50^{c}
Means^{1}		11.74^{bc}	14.46^{d}	12.58^{cd}	
200	1	15.30^{cd}	25.20^{e}	17.80^{d}	19.43^{e}
	7	13.13^{bc}	20.33^{d}	15.50^{cd}	16.32^{e}
	14	13.17^{bc}	18.23^{d}	13.68^{c}	15.03^{de}
	28	12.53^{bc}	16.10^{cd}	12.93^{bc}	13.85^{d}
	56	11.83^{bc}	14.60^{cd}	11.00^{bc}	12.48^{cd}
Means^{1}		13.19^{cd}	18.89^{e}	14.18^{d}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.62, P.I/P.E/T = 3.63, P.ET = 2.09] for Means^{1,2,3} respectively.

9. The effects of DMT-HFO extractions on the concentrated hydrochloric acid extracted organic P (C/HCl-P_o) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1093.23	273.31	250.79	<.01
INC/PER (I/P)	2	356.05	178.03	163.36	<.01
EX/TIME (E/T)	4	380.49	95.12	87.29	<.01
PHOSP.INC/PER (P.I/P)	8	128.02	16.00	14.68	<.01
PHOSP.EX/TIME (P.E/T)	16	41.32	2.58	2.37	0.04
INC/PER.EX/TIME (I.E/T)	8	35.86	4.48	4.11	<.01
PHOSP.INC/PER.EX/TIME	32	64.62	2.02	1.85	0.07
REPS	2	1.32	0.66	0.60	
Residual	150	163.47	1.09		
Total	224	2263.06			

SE = 1.04; CV = 9.8

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	7.00^{bc}	7.07^{bc}	7.77^{bc}	7.28^{cd}
	7	5.47^{b}	4.73^{ab}	5.67^{bc}	5.29^{bc}
	14	4.50^{ab}	4.55^{ab}	4.50^{ab}	4.52^{ab}
	28	4.00^{ab}	3.63^{ab}	3.97^{ab}	3.87^{ab}
	56	3.27^{ab}	2.57^{a}	3.27^{ab}	3.04^{a}
Means[1]		4.85^{ab}	4.51^{a}	5.04^{ab}	
25	1	7.30^{bc}	7.60^{bc}	8.52^{c}	7.81^{cd}
	7	5.67^{bc}	6.03^{bc}	7.03^{bc}	6.24^{bc}
	14	5.00^{ab}	5.17^{ab}	6.00^{bc}	5.39^{bc}
	28	4.40^{ab}	4.53^{ab}	5.33^{ab}	4.75^{b}
	56	3.47^{ab}	6.53^{bc}	4.23^{ab}	4.74^{b}
Means[1]		5.17^{ab}	5.97^{b}	6.22^{b}	
50	1	8.20^{bc}	8.53^{c}	9.70^{cd}	8.81^{de}
	7	7.13^{bc}	7.23^{bc}	8.87^{c}	7.64^{cd}
	14	6.00^{bc}	6.27^{bc}	7.57^{bc}	6.61^{c}
	28	5.50^{b}	5.07^{ab}	6.73^{bc}	5.77^{bc}
	56	4.83^{ab}	6.57^{bc}	5.93^{bc}	5.78^{bc}
Means[1]		6.33^{bc}	6.73^{bc}	7.70^{c}	

100	1	8.67^{c}	10.10^{cd}	12.35^{d}	10.37^{e}
	7	7.47^{bc}	8.27^{bc}	10.37^{cd}	8.70^{d}
	14	6.00^{bc}	7.27^{bc}	9.47^{cd}	7.58^{cd}
	28	6.07^{bc}	6.33^{bc}	8.33^{bc}	6.91^{c}
	56	5.28^{ab}	6.03^{bc}	7.27^{bc}	6.19^{bc}
Means^{1}		6.70^{bc}	7.60^{c}	9.56^{d}	
200	1	9.70^{cd}	12.37^{d}	13.53^{d}	11.87^{e}
	7	7.90^{bc}	9.83^{cd}	11.77^{d}	9.83^{de}
	14	7.60^{bc}	9.13^{cd}	10.40^{cd}	9.04^{de}
	28	6.50^{bc}	8.00^{bc}	9.60^{cd}	8.03^{cd}
	56	6.13^{bc}	6.67^{bc}	9.03^{cd}	7.28^{cd}
Means^{1}		7.57^{c}	9.20^{d}	10.87^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.28, P.I/P.E/T = 2.86, P.E/T = 1.65] for Means^{1,2,3} respectively.

10. The effects of DMT-HFO extractions on the extracted total organic P (TOT-P_o) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.(m.v.)	s.s.	m.s.	F	F pr.
PHOSP (P)	4	18063.21	4515.80	1353.50	<.01
INC/PER (I/P)	2	364.81	182.40	54.67	<.01
EX/TIME (E/T)	4	9253.74	2313.44	693.39	<.01
PHOSP.INC/PER (P.I/P)	8	1854.41	231.80	69.48	<.01
PHOSP.EX/TIME (P.E/T)	16	79.33	29.96	8.98	<.01
INC/PER.EX/TIME (I/P.E/T)	8	235.29	29.41	8.82	<.01
PHOSP.INCPER.EXTIME	32	646.83	20.21	6.06	<.01
REPS	2	8.38	4.19	1.26	
Residual	149(1)	497.12	3.34		
Total	223(1)	31015.26			

SE = 1.83; CV = 4.9

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	39.47^{e}	28.47^{cd}	31.42^{cd}	33.12^{de}
	7	31.60^{cd}	24.15^{bc}	28.60^{cd}	28.12^{c}
	14	26.52^{bc}	24.40^{bc}	25.20^{bc}	25.37^{bc}
	28	23.17^{b}	19.40^{ab}	23.75^{bc}	22.11^{ab}
	56	21.30^{ab}	17.68^{a}	20.57^{ab}	19.85^{a}
Means^{1}		28.41^{c}	22.82^{a}	25.91^{b}	
25	1	41.07^{e}	38.68^{e}	38.73^{e}	39.49^{f}
	7	35.27^{de}	32.75^{cd}	31.38^{cd}	33.13^{de}
	14	31.13^{cd}	32.23^{cd}	30.62^{cd}	31.33^{d}
	28	28.23^{c}	25.17^{bc}	26.43^{bc}	26.61^{bc}
	56	25.22^{bc}	22.43^{ab}	23.57^{b}	23.74^{b}
Means^{1}		32.18^{d}	30.25^{cd}	30.15^{cd}	
50	1	43.50^{ef}	44.10^{f}	45.93^{fg}	44.51^{g}
	7	37.30^{de}	39.30^{ef}	41.50^{ef}	39.37^{f}
	14	34.87^{de}	34.03^{de}	36.65^{de}	35.18^{e}
	28	33.47^{d}	30.07^{cd}	31.73^{cd}	31.76^{d}
	56	27.77^{bc}	25.30^{bc}	27.40^{bc}	26.82^{c}
Means^{1}		35.38^{e}	34.56^{e}	36.64^{ef}	
100	1	44.97^{fg}	54.62^{h}	59.95^{i}	53.18^{i}
	7	41.13^{ef}	47.72^{fg}	49.45^{g}	46.10^{g}
	14	37.00^{de}	43.33^{ef}	42.92^{ef}	41.08^{f}
	28	36.60^{de}	37.80^{de}	38.33^{de}	37.58^{ef}
	56	32.38^{cd}	28.57^{cd}	32.43^{cd}	31.13^{d}
Means^{1}		38.42^{f}	42.41^{g}	44.62^{g}	
200	1	48.53^{fg}	69.82^{j}	72.53^{j}	63.63^{k}
	7	46.40^{fg}	63.20^{i}	61.93^{i}	57.18^{j}
	14	43.17^{ef}	54.83^{h}	56.53^{h}	51.51^{h}
	28	40.93^{ef}	49.23^{g}	48.03^{fg}	46.07^{g}
	56	36.23^{de}	42.00^{ef}	39.52^{ef}	39.25^{f}
Means^{1}		43.05^{g}	55.82^{h}	55.71^{h}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 2.24, P.I/P.E/T = 5.01, P.E/T = 2.89] for Means^{1,2,3} respectively.

11. The effects of DMT-HFO extractions on the extracted total inorganic P (TOT-P_i) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.(m.v.)	s.s.	m.s.	F	F pr.
PHOSP (P)	4	884304.60	221076.15	3.64E+04	<.01
INC/PER (I/P)	2	15109.24	7554.62	1244.99	<.01
EX/TIME (E/T)	4	62779.61	15694.90	2586.50	<.01
PHOSP.INC/PER (P.I/P)	8	2621.83	327.73	54.01	<.01
PHOSP.EX/TIME (P.E/T)	16	1654.24	103.39	17.04	<.01
INC/PER.EX/TIME	8	987.15	123.39	20.34	<.01
PHOSP.INCPER.EXTIME	32	1745.25	54.54	8.99	<.01
REPS	2	35.46	17.73	3.00	
Residual	149(1)	904.13	6.07		
Total	223(1)	957442.83			

SE = 2.46; CV = 1.1

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	151.8^{f}	169.5^{hi}	190.2^{jk}	170.48^{g}
	7	142.2^{e}	160.3^{g}	170.2^{hi}	157.58^{e}
	14	125.4^{c}	145.3^{ef}	155.1^{fg}	141.93^{c}
	28	116.9^{b}	128.9^{cd}	132.9^{d}	126.24^{b}
	56	106.0^{a}	116.4^{b}	125.0^{c}	115.81^{a}
Means^{1}		128.5^{a}	144.1^{b}	154.7^{c}	
25	1	180.3^{ij}	193.9^{kl}	204.9^{m}	193.03^{j}
	7	165.0^{gh}	179.4^{ij}	189.6^{jk}	177.97^{h}
	14	150.7^{f}	167.6^{h}	175.8^{i}	164.68^{f}
	28	144.0^{ef}	155.8^{fg}	156.7^{fg}	152.16^{d}
	56	137.9^{de}	143.0^{e}	152.3^{f}	144.42^{c}
Means^{1}		155.6^{c}	168.0^{d}	175.8^{e}	
50	1	209.9^{m}	220.7^{n}	245.9^{qr}	225.48^{m}
	7	191.4^{kl}	204.1^{lm}	222.6^{n}	206.02^{l}
	14	191.0^{k}	200.3^{lm}	209.6^{m}	200.28^{k}
	28	168.3^{h}	184.1^{j}	197.8^{l}	183.43^{i}
	56	159.3^{g}	185.7^{jk}	194.2^{kl}	179.73^{h}
Means^{1}		184.0^{f}	199.0^{g}	214.0^{h}	

100	1	261.7^{s}	259.2^{s}	280.5^{t}	267.14^{q}
	7	252.2^{r}	247.9^{qr}	263.8^{s}	154.62^{de}
	14	234.5^{p}	250.0^{qr}	244.6^{q}	243.04^{p}
	28	224.6^{n}	225.6^{n}	244.9^{q}	231.72^{n}
	56	225.9^{np}	232.4^{p}	237.2^{p}	231.83^{n}
Means^{1}		239.8^{i}	243.0^{j}	254.2^{k}	
200	1	342.6^{x}	329.5^{w}	351.1^{y}	341.04^{v}
	7	331.7^{wx}	331.2^{wx}	337.3^{x}	333.39^{u}
	14	309.2^{v}	315.7^{v}	326.8^{w}	317.23^{t}
	28	302.3^{u}	303.7^{uv}	311.5^{v}	305.82^{s}
	56	295.4^{u}	295.9^{u}	302.0^{u}	297.75^{r}
Means^{1}		316.2^{l}	315.2^{l}	325.7^{m}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 3.02, P.I/P.E/T = 6.75, P.E/T = 3.90] for Means^{1,2,3} respectively.

12. The effects of DMT-HFO extractions on the extracted total soil P (TOT-P) of Rustenburg soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1.16E+06	2.89E+05	7.92E+04	<.01
INC/PER (I/P)	2	2.02E+04	1.01E+04	2769.64	<.01
EX/TIME (E/T)	4	1.20E+05	3.00E+04	8216.00	<.01
PHOSP.INC/PER (P.I/P)	8	8.31E+02	1.04E+02	28.47	<.01
PHOSP.EX/TIME (P.E/T)	16	1.09E+03	6.80E+01	18.66	<.01
INC/PER.EX/TIME(I/P.E/T)	8	1.63E+03	2.03E+02	55.79	<.01
PHOSP.INC/PER.EX/TIME	32	1.59E+03	4.98E+01	13.66	<.01
REPS	2	1.09E+01	5.47E+00	1.51	
Residual	150	5.47E+02	3.65E+00		
Total	224	1.30E+06			

SE = 1.91; CV = 0.8

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	191.3^{k}	197.9^{l}	221.6^{p}	203.60^{g}
	7	173.8^{hi}	184.5^{jk}	198.8^{l}	185.70^{e}
	14	151.9^{ef}	169.7^{h}	180.3^{ij}	167.31^{c}
	28	140.1^{c}	148.3^{e}	156.7^{f}	148.34^{b}
	56	127.3^{a}	134.1^{b}	145.6^{d}	135.66^{a}
Means^{1}		156.9^{a}	166.9^{b}	180.6^{c}	
25	1	221.4^{p}	232.6^{qr}	243.6^{s}	232.53^{j}
	7	200.3^{l}	212.1^{n}	220.9^{p}	211.10^{h}
	14	181.8^{j}	199.9^{l}	206.4^{m}	196.01^{f}
	28	172.2^{hi}	181.0^{ij}	183.1^{jk}	178.77^{d}
	56	163.1^{g}	165.5^{gh}	175.9^{i}	168.16^{c}
Means^{1}		187.7^{d}	198.2^{e}	206.0^{f}	
50	1	253.4^{t}	264.8^{uv}	291.8^{x}	169.99^{c}
	7	228.7^{q}	243.4^{s}	264.1^{u}	245.38^{k}
	14	225.9^{pq}	234.3^{r}	246.2^{s}	235.47^{j}
	28	201.8^{lm}	214.2^{n}	229.6^{qr}	215.18^{i}
	56	187.1^{k}	211.0^{m}	221.6^{p}	206.57^{g}
Means^{1}		219.4^{g}	233.5^{h}	250.7^{i}	
100	1	306.7^{y}	313.9^{z}	340.4^{BC}	320.32^{q}
	7	293.3^{x}	295.6^{x}	313.3^{z}	300.72^{p}
	14	271.6^{v}	293.4^{x}	287.5^{wx}	284.12^{n}
	28	261.2^{u}	263.4^{u}	283.3^{w}	269.30^{m}
	56	258.3^{tu}	261.0^{u}	269.6^{v}	262.96^{l}
Means^{1}		278.2^{j}	285.4^{k}	298.8^{l}	
200	1	391.1^{I}	399.3^{J}	423.6^{K}	404.67^{v}
	7	378.1^{G}	394.4^{I}	399.2^{J}	390.57^{u}
	14	352.3^{D}	370.6^{F}	384.1^{H}	368.99^{t}
	28	343.2^{C}	352.9^{D}	359.6^{E}	351.89^{s}
	56	331.6^{A}	337.9^{B}	341.5^{BC}	337.00^{r}
Means^{1}		359.3^{m}	371.0^{n}	381.6^{p}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 2.34, P.I/P.E/T = 5.23, P.E/T = 3.02] for Means^{1,2,3} respectively.

B: LOSKOP SOIL

13 The effects of DMT-HFO extractions on the extractable solution P of Loskop soil as influenced by the added P, and the incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	112882.98	28220.75	1.85E+04	<.01
INC/PER (I/P)	2	6665.50	3332.75	2184.57	<.01
EX/TIME (E/T)	4	24763.29	6190.82	4057.99	<.01
PHOSP.INC/PER (P.I/P)	8	3948.59	493.57	323.53	<.01
PHOSP.EX/TIME (P.E/T)	16	8796.72	549.80	360.38	<.01
INC/PER.EX/TIME (I/P.E/T)	8	390.61	48.83	32.00	<.01
PHOSP.INC/PER.EX/TIME	32	642.11	20.07	13.15	<.01
REPS	2	7.98	3.99	2.67	
Residual	150	228.84	1.53		
Total	224	158318.63			

SE = 1.24; CV = 3.3

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	6.30^{ab}	5.22^{ab}	4.13^{a}	5.22^{a}
	7	8.42^{b}	6.72^{ab}	5.82^{ab}	6.99^{ab}
	14	10.50^{bc}	7.72^{b}	6.50^{ab}	8.24^{b}
	28	12.75^{c}	9.30^{bc}	8.55^{b}	10.20^{c}
	56	14.70^{cd}	12.20^{c}	12.17^{c}	13.02^{d}
Means[1]		10.53^{b}	8.23^{a}	7.43^{a}	
25	1	13.93^{cd}	12.63^{c}	10.13^{bc}	12.23^{d}
	7	20.50^{e}	16.77^{d}	14.80^{cd}	17.36^{e}
	14	24.03^{f}	22.22^{ef}	17.67^{de}	21.31^{g}
	28	32.25^{h}	26.88^{fg}	24.17^{f}	27.77^{i}
	56	35.97^{i}	32.87^{hi}	27.75^{g}	31.53^{j}
Means[1]		24.94^{e}	22.27^{d}	18.90^{c}	
50	1	27.38^{fg}	16.72^{d}	13.43^{cd}	19.18^{f}
	7	30.17^{gh}	22.53^{ef}	20.85^{ef}	24.52^{h}
	14	35.58^{hi}	26.52^{fg}	25.83^{fg}	29.31^{i}
	28	40.35^{jk}	32.40^{h}	30.50^{gh}	34.42^{k}
	56	45.65^{k}	42.03^{jk}	38.58^{ij}	42.09^{m}
Means[1]		35.83^{g}	28.04^{f}	25.84^{e}	

100	1	46.68^{kl}	24.27^{f}	18.73^{de}	29.89^{j}
	7	53.67^{m}	32.87^{hi}	33.43^{hi}	39.99^{l}
	14	60.05^{np}	43.42^{k}	40.33^{jk}	47.93^{n}
	28	71.05^{r}	58.53^{n}	56.50^{mn}	62.03^{p}
	56	77.53^{st}	71.67^{r}	63.17^{p}	70.79^{q}
Means[1]		61.80^{j}	46.15^{i}	42.43^{h}	
200	1	67.22^{q}	39.63^{j}	35.20^{hi}	47.35^{n}
	7	80.17^{t}	54.37^{m}	49.63^{l}	61.39^{p}
	14	92.80^{v}	70.17^{qr}	60.50^{np}	74.49^{r}
	28	102.50^{w}	88.43^{u}	76.17^{s}	89.03^{s}
	56	115.87^{y}	108.50^{x}	92.00^{r}	105.46^{t}
Means[1]		91.71^{l}	72.22^{k}	62.70^{j}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.51, P.I/P.E/T = 3.39, P.E/T = 1.95] for Means[1,2,3] respectively.

14. The effects of DMT-HFO extractions on the bicarbonate extracted inorganic P (-HCO_3-P_i) of Loskop soil as influenced by the added P,. and the incubation period

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	36593.89	9148.47	1.01E+04	<.01
INC/PER (I/P)	2	3735.67	1867.84	2066.95	<.01
EX/TIME (E/T)	4	5335.72	1333.93	1476.13	<.01
PHOSP.INC/PER (P.I/P)	8	1708.39	213.55	236.31	<.01
PHOSP.EX/TIME (P.E/T)	16	2081.44	130.09	143.96	<.01
INC/PER.EX/TIME (I/P.E/T)	8	1151.70	143.96	159.31	<.01
PHOSP.INC/PER.EX/TIME	32	644.78	20.15	22.30	<.01
REPS	2	5.36	2.68	3.05	
Residual	150	135.55	0.90		
Total	224	51387.16			

SE = 0.95; CV = 4.3

(ii). Table of means

ADDED-P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	12.27^{de}	11.27^{de}	9.60^{cd}	11.04^{de}
	7	12.00^{de}	10.47^{d}	7.77^{c}	10.08^{d}
	14	9.07^{cd}	7.80^{c}	6.50^{bc}	7.79^{c}
	28	7.47^{c}	5.90^{bc}	4.33^{b}	5.90^{bc}
	56	5.80^{bc}	3.27^{ab}	1.53^{a}	3.53^{a}
Means^{1}		9.32^{c}	7.74^{b}	5.95^{a}	
25	1	18.87^{fg}	13.57^{e}	12.43^{de}	14.96^{g}
	7	14.43^{ef}	11.00^{de}	9.67^{cd}	11.70^{e}
	14	12.00^{de}	9.53^{cd}	8.33^{cd}	9.95^{d}
	28	8.57^{cd}	7.28^{c}	4.83^{bc}	6.89^{c}
	56	7.57^{c}	4.23^{b}	3.63^{ab}	5.14^{b}
Means^{1}		12.29^{d}	9.12^{c}	7.78^{b}	
50	1	25.00^{hi}	20.87^{gh}	14.13^{ef}	20.00^{i}
	7	22.77^{h}	15.33^{ef}	12.93^{de}	17.01^{h}
	14	16.50^{f}	13.00^{de}	10.67^{de}	13.39^{f}
	28	13.27^{e}	10.97^{de}	7.53^{c}	10.59^{de}
	56	9.17^{cd}	8.10^{cd}	5.83^{bc}	7.70^{c}
Means^{1}		17.34^{f}	13.65^{e}	10.22^{c}	
100	1	42.73^{lm}	35.47^{k}	22.10^{gh}	33.43^{k}
	7	33.13^{jk}	24.77^{hi}	16.55^{f}	24.82^{j}
	14	28.30^{i}	20.13^{g}	13.77^{e}	20.73^{i}
	28	20.50^{gh}	15.07^{ef}	11.07^{de}	15.55^{gh}
	56	15.33^{ef}	11.93^{de}	8.53^{cd}	11.93^{ef}
Means^{1}		35.00^{j}	24.27^{h}	19.40^{f}	
200	1	78.00^{q}	56.33^{p}	44.83^{m}	62.06^{p}
	7	58.77^{p}	46.10^{m}	32.55^{j}	48.47^{n}
	14	50.47^{n}	40.93^{l}	27.43^{i}	43.61^{m}
	28	43.53^{lm}	32.70^{j}	21.93^{gh}	38.06^{l}
	56	26.83^{i}	28.07^{i}	17.23^{f}	32.71^{k}
Means^{1}		51.52^{l}	40.83^{k}	28.79^{i}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.17, P.I/P.E/T = 2.61, PE = 1.50] for Means^{1,2,3} respectively.

15. The effects of DMT-HFO extractions on the hydroxide extracted inorganic P (-OH-P_i) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	58740.55	14685.14	1.12E+04	<.01
INC/PER (I/P)	2	3828.98	1914.49	1459.83	<.01
EX/TIME (E/T)	4	10806.55	2701.63	2060.04	<.01
PHOSP.INC/PER (P.I/P)	8	1176.93	147.12	112.18	<.01
PHOSP.EX/TIME (P.E/T)	16	1029.49	64.34	49.06	<.01
INC/PER.EX/TIME (I/P.E/T)	8	610.72	76.34	58.21	<.01
PHOSP.INC/PER.EX/TIME	32	658.17	20.57	15.68	<.01
REPS	2	10.87	5.44	4.33	
Residual	150	196.72	1.31		
Total	224	77048.09			

SE = 1.15; CV = 2.9

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	25.33^{de}	29.13^{ef}	32.93^{fg}	29.13^{e}
	7	20.83^{c}	25.13^{de}	28.87^{e}	24.94^{d}
	14	19.45^{bc}	21.43^{cd}	25.32^{de}	22.07^{c}
	28	15.93^{ab}	19.27^{bc}	21.60^{cd}	18.93^{b}
	56	13.40^{a}	17.57^{b}	19.30^{bc}	16.76^{a}
Means[1]		18.99^{a}	22.51^{b}	25.60^{c}	
25	1	28.13^{e}	33.27^{fg}	35.10^{g}	32.17^{g}
	7	24.13^{d}	27.67^{e}	32.27^{fg}	28.02^{f}
	14	22.07^{cd}	23.60^{cd}	28.98^{ef}	24.88^{e}
	28	18.13^{bc}	21.10^{cd}	23.45^{cd}	20.89^{c}
	56	14.72^{ab}	18.75^{bc}	20.60^{bc}	18.02^{ab}
Means[1]		21.44^{b}	24.88^{c}	28.08^{d}	
50	1	31.77^{f}	36.93^{gh}	41.10^{hi}	36.60^{g}
	7	28.30^{e}	32.27^{fg}	35.00^{g}	31.86^{f}
	14	25.83^{de}	29.97^{ef}	31.75^{f}	29.18^{e}
	28	22.67^{cd}	26.93^{de}	28.50^{e}	26.03^{d}
	56	20.82^{c}	22.57^{cd}	24.63^{de}	22.67^{c}
Means[1]		25.88^{c}	29.73^{e}	32.20^{f}	

100	1	37.20^{gh}	47.00^{ij}	56.30^{k}	46.83^{j}
	7	32.90^{fg}	40.63^{h}	48.53^{j}	40.69^{h}
	14	29.50^{ef}	38.43^{h}	44.00^{i}	37.31^{g}
	28	25.77^{de}	33.67^{fg}	36.78^{gh}	32.07^{f}
	56	22.00^{cd}	29.25^{ef}	32.63^{fg}	27.96^{e}
Means$_1$		29.47^{d}	37.80^{g}	43.65^{h}	
200	1	65.93^{mn}	78.60^{q}	86.53^{r}	77.02^{n}
	7	62.70^{lm}	67.43^{n}	73.20^{p}	67.78^{m}
	14	56.07^{k}	59.77^{l}	63.53^{m}	59.79^{l}
	28	49.80^{j}	51.07^{jk}	54.07^{k}	51.65^{k}
	56	39.45^{h}	46.20^{ij}	46.83^{ij}	44.16^{i}
Means^1		54.79^{i}	60.61^{j}	64.83^{k}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.40, P.I/P.E/T = 3.14, PE = 1.81] for Means^{1,2,3} respectively.

16. Effects of DMT-HFO extractions on the dilute hydrochloric acid extracted inorganic P (D/HCl-P$_i$) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1746.35	436.59	446.54	<.01
INC/PER (I/P)	2	203.34	101.67	103.99	<.01
EX/TIME (E/T)	4	562.35	140.59	143.79	<.01
PHOSP.INC/PER (P.I/P)	8	51.51	6.44	6.59	<.01
PHOSP.EX/TIME (P.E/T)	16	134.13	8.38	8.57	<.01
INC/PER.EX/TIME (I/P.E/T)	8	23.34	2.92	2.98	0.04
PHOSP.INC/PER.EX/TIME	32	40.40	1.26	1.29	0.15
REPS	2	1.13	0.56	0.57	
Residual	150	146.66	0.98		
Total	224	2908.09			

SE = 0.99; CV = 11.0

(ii). Table of means

ADDED P ($mg\ kg^{-1}$)	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	6.13^{ab}	6.40^{ab}	6.65^{ab}	6.39^{b}
	7	4.87^{ab}	5.77^{ab}	6.30^{ab}	5.65^{ab}
	14	4.72^{ab}	5.55^{ab}	5.60^{ab}	5.29^{ab}
	28	4.50^{ab}	5.33^{ab}	5.50^{ab}	5.11^{ab}
	56	4.30^{a}	4.47^{ab}	5.30^{ab}	4.69^{a}
Means^{1}		4.90^{a}	5.50^{ab}	5.87^{ab}	
25	1	7.90^{bc}	8.47^{bc}	9.13^{bc}	8.50^{c}
	7	6.80^{ab}	8.27^{bc}	7.63^{bc}	7.57^{bc}
	14	6.47^{ab}	7.10^{b}	7.47^{bc}	7.01^{bc}
	28	5.32^{ab}	6.13^{ab}	6.93^{ab}	6.13^{ab}
	56	4.93^{ab}	5.27^{ab}	6.30^{ab}	5.50^{ab}
Means^{1}		6.28^{b}	7.05^{b}	7.49^{bc}	
50	1	8.77^{bc}	10.00^{c}	12.27^{cd}	10.35^{d}
	7	6.93^{ab}	9.87^{c}	11.00^{cd}	9.27^{cd}
	14	6.67^{ab}	7.60^{bc}	9.37^{bc}	7.88^{bc}
	28	6.00^{ab}	7.60^{bc}	8.37^{bc}	7.32^{bc}
	56	5.42^{ab}	7.17^{bc}	8.27^{bc}	6.95^{bc}
Means^{1}		6.76^{b}	8.45^{c}	9.86^{d}	
100	1	12.80^{d}	14.80^{de}	16.02^{e}	14.54^{f}
	7	9.20^{bc}	12.73^{d}	13.40^{de}	11.78^{de}
	14	8.50^{bc}	10.53^{cd}	12.20^{cd}	10.41^{d}
	28	7.80^{bc}	9.47^{bc}	11.13^{cd}	9.47^{cd}
	56	7.00^{ab}	8.28^{bc}	10.60^{cd}	8.63^{c}
Means^{1}		9.06^{cd}	11.16^{e}	12.67^{f}	
200	1	14.07^{de}	18.93^{f}	19.40^{f}	17.47^{g}
	7	12.33^{cd}	14.27^{de}	15.20^{de}	13.93^{ef}
	14	11.00^{cd}	12.20^{cd}	14.13^{de}	12.44^{e}
	28	9.67^{bc}	11.60^{cd}	13.00^{d}	11.42^{de}
	56	9.10^{bc}	10.17^{cd}	12.73^{d}	10.67^{d}
Means^{1}		11.23^{e}	13.43^{f}	14.89^{g}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.21, P.I/P.E/T = 2.71, P.E/T = 1.56] for Means^{1,2,3} respectively.

17. The effects of DMT-HFO extractions on the concentrated hydrochloric acid extracted inorganic P (C/HCl-P_i) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	8481.59	2120.40	1186.76	<.01
INC/PER (I/P)	2	4246.39	2123.20	1188.33	<.01
EX/TIME (E/T)	4	2836.08	709.02	396.83	<.01
PHOSP.INC/PER (P.I/P)	8	1058.88	132.36	74.08	<.01
PHOSP.EX/TIME (P.E/T)	16	121.83	7.61	4.26	<.01
INC/PER.EX/TIME (I/P.E/T)	8	371.98	46.50	26.02	<.01
PHOSP.INC/PER.EX/TIME	32	138.89	4.34	2.43	<.01
REPS	2	3.70	1.85	1.03	
Residual	150	268.01	1.79		
Total	224	17523.65			

SE = 1.34; CV = 3.5

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIODS (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	31.10^{bc}	32.60^{bc}	38.00^{d}	33.90^{d}
	7	29.27^{ab}	30.00^{bc}	32.67^{bc}	30.65^{bc}
	14	27.87^{ab}	29.67^{b}	31.93^{bc}	29.82^{bc}
	28	26.20^{ab}	27.20^{ab}	29.67^{b}	27.69^{ab}
	56	25.87^{a}	26.13^{ab}	27.27^{ab}	26.42^{a}
Means^{1}		28.06^{a}	29.12^{ab}	31.91^{bc}	
25	1	32.53^{bc}	34.67^{cd}	40.27^{de}	35.82^{de}
	7	30.33^{bc}	31.33^{bc}	35.33^{cd}	32.33^{cd}
	14	28.80^{ab}	30.00^{bc}	32.93^{bc}	30.58^{bc}
	28	27.33^{ab}	29.00^{ab}	30.93^{bc}	29.09^{bc}
	56	26.27^{ab}	26.60^{ab}	28.47^{ab}	27.11^{ab}
Means^{1}		29.05^{ab}	30.32^{b}	33.59^{c}	
50	1	33.67^{c}	36.87^{cd}	41.93^{e}	37.49^{e}
	7	32.60^{bc}	34.47^{cd}	38.27^{de}	35.11^{de}
	14	30.53^{bc}	32.27^{bc}	34.93^{cd}	32.58^{cd}
	28	28.93^{ab}	31.53^{bc}	32.60^{bc}	31.02^{c}
	56	27.93^{ab}	28.33^{ab}	30.00^{bc}	28.75^{b}
Means^{1}		30.73^{b}	32.69^{c}	35.55^{d}	

100	1	35.53^{cd}	40.13^{de}	48.47^{fg}	41.38^{f}
	7	34.60^{cd}	38.33^{de}	43.60^{ef}	38.84^{e}
	14	33.60^{c}	37.67^{d}	39.93^{de}	37.07^{e}
	28	31.27^{bc}	35.93^{cd}	35.93^{cd}	34.38^{d}
	56	30.60^{bc}	31.93^{bc}	33.67^{c}	32.07^{cd}
Means[1]		33.12^{c}	36.80^{de}	40.32^{f}	
200	1	40.53^{de}	50.27^{g}	59.27^{h}	50.02^{i}
	7	39.60^{de}	49.67^{fg}	58.00^{h}	49.09^{hi}
	14	37.93^{d}	48.67^{fg}	56.67^{h}	47.76^{h}
	28	36.27^{cd}	46.33^{f}	52.53^{g}	45.04^{g}
	56	34.77^{cd}	44.60^{ef}	50.33^{g}	43.23^{fg}
Means[1]		37.82^{e}	47.91^{g}	55.36^{h}	

N.B. Means with the same superscripts are not significantly different (P = 0.001) LSD (Fisher) [P.I/P = 1.64, P.I/P.E/T = 3.66, P.E/T = 2.12] for Means[1,2,3] respectively.

18. The effects of DMT-HFO extractions on the concentrated sulphuric acid extracted residual P (H_2SO_4-P_i) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	3268.75	817.19	951.47	<.01
INC/PER (I/P)	2	2975.79	1487.90	1732.40	<.01
EX/TIME (E/T)	4	1256.81	314.20	365.83	<.01
PHOSP.INC/PER (P.I/P)	8	1514.55	189.32	220.43	<.01
PHOSP.EX/TIME (P.E/T)	16	43.48	2.72	3.16	<.01
INC/PER.EX/TIME (I/P.E/T)	8	230.93	28.87	33.61	<.01
PHOSP.INC/PER.EX/TIME	32	114.67	3.58	4.17	<.01
REPS	2	3.84	1.92	2.27	
Residual	150	128.83	0.86		
Total	224	9533.81			

SE = 0.93; CV = 2.6

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS Days	INCUBATION PERIOD (DAYS) 1^2	120^2	240^2	Means^3
0	1	45.75^{hi}	47.00^{i}	47.75^{ij}	46.83^{i}
	7	34.33^{de}	35.17^{e}	41.48^{g}	36.99^{f}
	14	32.87^{de}	30.75^{cd}	35.00^{e}	32.87^{d}
	28	25.75^{ab}	28.67^{bc}	33.00^{de}	29.14^{bc}
	56	23.78^{a}	24.67^{ab}	30.75^{cd}	26.40^{a}
Means^1		32.50^{a}	33.25^{a}	37.60^{c}	
25	1	46.92^{i}	49.00^{ij}	52.00^{jk}	49.31^{j}
	7	35.67^{e}	38.80^{f}	45.75^{hi}	40.07^{g}
	14	33.63^{de}	33.00^{de}	37.25^{ef}	34.63^{e}
	28	25.95^{ab}	30.08^{c}	34.00^{de}	30.01^{c}
	56	24.50^{ab}	25.83^{ab}	32.17^{d}	27.50^{ab}
Means^1		33.33^{a}	35.34^{b}	40.23^{d}	
50	1	48.17^{ij}	51.33^{jk}	56.42^{l}	51.97^{k}
	7	36.33^{ef}	41.50^{g}	49.67^{j}	42.50^{h}
	14	34.87^{e}	38.25^{f}	44.25^{h}	39.12^{g}
	28	28.42^{bc}	31.92^{cd}	38.50^{f}	32.95^{d}
	56	25.68^{ab}	27.00^{b}	34.17^{de}	28.28^{b}
Means^1		34.69^{b}	38.00^{c}	44.20^{f}	
100	1	50.67^{jk}	55.67^{l}	61.00^{m}	55.78^{l}
	7	39.67^{fg}	47.50^{ij}	54.08^{kl}	47.08^{i}
	14	37.60^{ef}	40.33^{fg}	50.67^{jk}	42.87^{h}
	28	33.58^{de}	34.42^{de}	46.00^{h}	38.00^{fg}
	56	29.58^{c}	30.50^{cd}	40.33^{fg}	33.47^{de}
Means^1		38.22^{c}	41.68^{e}	50.42^{g}	
200	1	53.87^{kl}	64.83^{n}	75.33^{q}	64.68^{m}
	7	44.00^{gh}	57.00^{l}	73.08^{q}	58.03^{m}
	14	43.90^{gh}	53.00^{k}	68.42^{p}	55.11^{l}
	28	40.60^{fg}	47.87^{ij}	64.83^{n}	51.10^{k}
	56	37.22^{ef}	42.33^{gh}	62.67^{mn}	47.41^{i}
Means^1		43.92^{f}	53.01^{h}	68.87^{i}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.14, P.I/P.E/T = 2.54, P.E/T = 1.47] for Means^{1,2,3} respectively.

19. The effects of DMT-HFO extractions on the bicarbonate extracted organic P ((-HCO_3-P_o) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1962.17	490.54	548.15	<.01
INC/PER (I/P)	2	65.36	32.68	36.52	<.01
EX/TIME (E/T)	4	1154.12	288.53	322.42	<.01
PHOSP.INC/PER (P.I/P)	8	49.02	6.13	6.85	<.01
PHOSP.EX/TIME (P.E/T)	16	173.55	10.85	12.12	<.01
INC/PER.EX/TIME (I/P.E/T)	8	325.84	40.73	45.51	<.01
PHOSP.INC/PER.EX/TIME	32	150.28	4.70	5.25	<.01
REPS	2	0.08	0.04	0.04	
Residual	150	134.24	0.89		
Total	224	4014.59			

SE = 0.95; CV = 10.9

(ii) Table of means

ADDED.P. (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIODS (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	7.07^{c}	6.93^{c}	6.00^{bc}	6.67^{cd}
	7	4.63^{bc}	4.03^{ab}	4.63^{bc}	4.43^{bc}
	14	3.13^{ab}	3.53^{ab}	3.43^{ab}	3.36^{b}
	28	2.87^{ab}	2.00^{ab}	2.07^{ab}	2.31^{ab}
	56	1.53^{a}	1.50^{a}	2.05^{ab}	1.69^{a}
Means^{1}		3.85^{a}	3.60^{a}	3.64^{a}	
25	1	8.00^{cd}	11.17^{de}	8.43^{cd}	9.20^{ef}
	7	5.70^{bc}	6.40^{bc}	7.27^{c}	6.46^{cd}
	14	4.27^{b}	5.58^{bc}	6.40^{bc}	5.42^{c}
	28	2.97^{ab}	3.00^{ab}	4.63^{bc}	3.53^{b}
	56	1.77^{ab}	2.17^{ab}	3.50^{ab}	2.48^{ab}
Means^{1}		4.54^{ab}	5.66^{b}	6.05^{b}	
50	1	8.47^{cd}	11.67^{de}	10.93^{de}	10.36^{f}
	7	4.90^{bc}	6.93^{c}	8.37^{cd}	6.73^{cd}
	14	4.50^{bc}	5.33^{bc}	7.07^{c}	5.63^{cd}
	28	3.07^{ab}	4.03^{ab}	5.33^{bc}	4.14^{bc}
	56	2.50^{ab}	3.00^{ab}	4.77^{bc}	3.42^{b}
Means^{1}		4.69^{ab}	6.19^{bc}	7.29^{c}	

100	1	9.93^{d}	13.20^{e}	11.10^{de}	11.41^{fg}
	7	7.87^{cd}	8.77^{cd}	9.18^{cd}	11.94^{g}
	14	6.57^{bc}	6.53^{bc}	8.07^{cd}	7.06^{d}
	28	5.50^{bc}	4.80^{bc}	7.40^{cd}	5.90^{cd}
	56	4.00^{ab}	3.67^{ab}	6.00^{bc}	4.56^{bc}
Means[1]		6.77^{bc}	7.39^{c}	10.35^{e}	
200	1	10.80^{de}	13.65^{e}	12.77^{e}	12.41^{g}
	7	8.00^{cd}	10.90^{de}	11.32^{de}	10.07^{ef}
	14	7.20^{c}	8.33^{cd}	10.20^{de}	8.58^{e}
	28	6.53^{bc}	5.97^{bc}	8.63^{cd}	7.04^{d}
	56	5.00^{bc}	4.80^{bc}	7.77^{cd}	5.86^{cd}
Means[1]		7.51^{c}	8.73^{d}	10.14^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.16, P.I/P.E/T = 2.59, P.E/T = 1.50] for Means[1,2,3] respectively.

20. The effects of DMT-HFO extractions on the hydroxide extracted organic P (-OH-P_o) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	3433.91	858.48	654.59	<.01
INC/PER (I/P)	2	127.35	63.68	48.55	<.01
EX/TIME (E/T)	4	845.08	211.27	161.09	<.01
PHOSP.INC/PER (P.I/P)	8	207.03	25.88	19.73	<.01
PHOSP.EX/TIME (P.E/T)	16	73.74	4.61	3.51	<.01
INC/PER.EX/TIME (I/P.E/T)	8	122.41	15.30	11.67	<.01
PHOSP.INC/PER.EX/TIME	32	72.69	2.27	1.73	0.02
REPS	2	1.48	0.74	0.56	
Residual	150	196.72	1.31		
Total	224	5078.94			

SE = 1.15; CV = 8.7

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	9.20^{c}	8.13^{bc}	7.11^{bc}	8.15^{bc}
	7	7.10^{bc}	6.07^{bc}	6.93^{bc}	6.70^{b}
	14	6.35^{bc}	4.97^{ab}	6.22^{bc}	5.85^{ab}
	28	5.00^{ab}	4.33^{ab}	5.00^{ab}	4.78^{ab}
	56	4.77^{ab}	2.83^{a}	4.70^{ab}	4.10^{a}
Means[1]		6.48^{ab}	5.27^{a}	5.99^{ab}	
25	1	11.93^{cd}	10.20^{cd}	9.17^{bc}	10.43^{cd}
	7	9.47^{cd}	8.20^{bc}	8.27^{bc}	8.65^{c}
	14	8.97^{bc}	6.13^{bc}	7.88^{bc}	7.66^{bc}
	28	6.53^{bc}	5.37^{ab}	7.15^{bc}	6.35^{b}
	56	6.62^{bc}	4.32^{ab}	6.03^{b}	5.66^{ab}
Means[1]		8.70^{b}	6.84^{b}	7.70^{b}	
50	1	12.43^{d}	11.40^{cd}	11.43^{cd}	11.75^{d}
	7	10.30^{cd}	10.07^{cd}	10.57^{cd}	10.31^{cd}
	14	9.57^{cd}	8.50^{bc}	8.78^{bc}	8.95^{c}
	28	8.27^{bc}	6.53^{bc}	7.83^{bc}	7.54^{bc}
	56	7.92^{bc}	5.37^{ab}	7.37^{bc}	6.72^{b}
Means[1]		9.60^{bc}	8.37^{b}	9.20^{b}	
100	1	13.53^{de}	14.27^{de}	14.40^{de}	14.07^{e}
	7	11.30^{cd}	12.17^{cd}	12.40^{d}	11.96^{d}
	14	10.80^{cd}	10.83^{cd}	10.67^{cd}	10.77^{d}
	28	9.50^{cd}	9.13^{bc}	8.88^{bc}	9.17^{cd}
	56	8.00^{bc}	8.35^{bc}	8.30^{bc}	8.22^{bc}
Means[1]		10.63^{c}	10.95^{cd}	10.93^{cd}	
200	1	15.13^{de}	17.07^{e}	15.93^{e}	16.04^{f}
	7	13.83^{de}	14.83^{de}	14.37^{de}	14.34^{e}
	14	11.47^{cd}	12.80^{de}	12.07^{cd}	12.11^{d}
	28	10.80^{cd}	11.60^{cd}	11.53^{cd}	11.31^{d}
	56	10.02^{cd}	10.40^{cd}	10.83^{cd}	10.42^{cd}
Means[1]		12.25^{d}	13.34^{d}	12.95^{d}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 1.40, P.I/P.E/T = 3.14, P.E/T = 1.81] for Means[1,2,3] respectively.

21. The effects of DMT-HFO extractions on the concentrated hydrochloric acid extracted organic P (C/HCl-P_o) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	794.39	198.60	234.48	<.01
INC/PER (I/P)	2	365.47	182.74	215.75	<.01
EX/TIME (E/T)	4	191.48	47.87	56.52	<.01
PHOSP.INC/PER (P.I/P)	8	126.47	15.81	18.67	<.01
PHOSP.EX/TIME (P.E/T)	16	51.72	3.23	3.82	<.01
INC/PER.EX/TIME (I/P.E/T)	8	53.52	6.69	7.90	<.01
PHOSP.INC/PER.EX/TIME	32	37.30	1.17	1.38	0.11
REPS	2	0.27	0.13	0.16	
Residual	150	127.05	0.85		
Total	224	1747.40			

SE = 0.92; CV = 12.4

(ii). Table of means

ADDED P ($mg\ kg^{-1}$)	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1[2]	120[2]	240[2]	Means[3]
0	1	5.07^{bc}	5.40^{bc}	6.40^{bc}	5.62^{bc}
	7	3.93^{ab}	4.33^{ab}	4.93^{bc}	4.40^{b}
	14	2.80^{ab}	4.00^{ab}	4.27^{ab}	3.69^{ab}
	28	2.40^{ab}	3.67^{ab}	3.20^{ab}	3.09^{ab}
	56	2.23^{a}	3.53^{ab}	2.67^{ab}	2.81^{a}
Means[1]		3.29^{a}	4.19^{ab}	4.29^{ab}	
25	1	5.97^{bc}	6.27^{bc}	7.07^{bc}	6.44^{c}
	7	4.33^{ab}	5.50^{bc}	6.00^{bc}	5.28^{bc}
	14	3.07^{ab}	5.08^{bc}	5.67^{bc}	4.61^{bc}
	28	2.67^{ab}	4.50^{ab}	4.50^{ab}	3.89^{ab}
	56	2.40^{ab}	4.00^{ab}	4.13^{ab}	3.51^{ab}
Means[1]		3.69^{a}	5.07^{b}	5.47^{bc}	
50	1	6.17^{bc}	7.63^{cd}	10.93^{d}	8.24^{d}
	7	4.73^{ab}	7.20^{bc}	8.33^{cd}	6.75^{cd}
	14	3.90^{ab}	6.80^{bc}	7.33^{c}	6.01^{c}
	28	3.50^{ab}	5.60^{bc}	6.40^{bc}	5.17^{bc}
	56	3.20^{ab}	5.00^{bc}	5.33^{bc}	4.51^{b}
Means[1]		4.30^{ab}	6.45^{c}	7.66^{d}	

100	1	6.50^{bc}	10.57^{d}	12.20^{de}	9.76^{e}
	7	5.35^{bc}	9.00^{cd}	10.07^{d}	8.14^{d}
	14	4.80^{b}	8.00^{cd}	8.73^{cd}	7.18^{cd}
	28	4.07^{ab}	6.93^{bc}	7.33^{c}	6.11^{c}
	56	3.87^{ab}	6.07^{bc}	6.33^{bc}	5.42^{bc}
Means[1]		4.92^{b}	8.11^{de}	8.93^{e}	
200	1	7.47^{c}	13.48^{e}	12.47^{de}	11.14^{e}
	7	6.50^{bc}	11.00^{de}	10.60^{d}	9.37^{de}
	14	6.00^{bc}	9.67^{cd}	9.27^{cd}	8.31^{de}
	28	5.00^{bc}	8.00^{cd}	8.47^{cd}	7.16^{cd}
	56	4.57^{ab}	7.00^{bc}	8.27^{cd}	6.61^{c}
Means[1]		5.91^{bc}	9.83^{e}	9.82^{e}	

N.B. Means with the same superscripts are not significantly different (P = 0.01) LSD (Fisher) [P.I/P = 1.13, P.I/P.E/T = 2.52, P.E/T = 1.46] for Means[1,2,3] respectively.

22. The effects of DMT-HFO extractions on the extracted total organic P (TOT-P_o) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	17135.48	4283.87	1436.79	<.01
INC/PER (I/P)	2	1139.91	569.95	191.16	<.01
EX/TIME (E/T)	4	5888.81	1472.20	493.77	<.01
PHOSP.INC/PER (P.I/P)	8	854.80	106.85	35.84	<.01
PHOSP.EX/TIME (P.E/T)	16	685.15	42.82	14.36	<.01
INC/PER.EX/TIME (I/P.E/T)	8	952.53	119.07	39.93	<.01
PHOSP.INC/PER.EX/TIME	32	526.38	16.45	5.52	<.01
REPS	2	0.63	0.31	0.10	
Residual	150	447.23	2.98		
Total	224	27630.29			

SE = 1.73; CV = 5.9

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	23.33^{c}	20.47^{bc}	22.51^{bc}	22.10^{c}
	7	20.67^{bc}	17.93^{b}	19.50^{bc}	19.37^{bc}
	14	19.28^{bc}	15.50^{ab}	16.85^{ab}	17.21^{b}
	28	17.27^{ab}	15.37^{ab}	16.33^{ab}	16.32^{ab}
	56	14.53^{ab}	13.17^{a}	15.43^{ab}	14.38^{a}
Means^{1}		19.02^{b}	16.49^{a}	18.12^{ab}	
25	1	25.90^{cd}	29.63^{d}	30.67^{de}	28.74^{e}
	7	24.50^{cd}	21.60^{bc}	26.53^{cd}	24.21^{d}
	14	21.30^{bc}	19.37^{bc}	23.28^{c}	21.32^{c}
	28	20.17^{bc}	18.82^{bc}	20.45^{bc}	19.81^{bc}
	56	17.78^{ab}	15.48^{ab}	18.77^{bc}	17.34^{b}
Means^{1}		21.93^{c}	20.98^{bc}	23.94^{c}	
50	1	28.07^{d}	39.70^{fg}	44.30^{g}	37.36^{gh}
	7	30.93^{de}	28.20^{d}	36.27^{ef}	31.80^{f}
	14	28.47^{d}	24.63^{cd}	32.18^{de}	28.43^{e}
	28	24.40^{cd}	21.37^{bc}	28.57^{d}	24.78^{d}
	56	19.82^{bc}	18.27^{b}	22.47^{bc}	20.18^{c}
Means^{1}		26.34^{d}	26.43^{d}	32.76^{e}	
100	1	31.97^{de}	50.03^{h}	49.70^{h}	43.90^{i}
	7	36.90^{ef}	37.93^{ef}	43.65^{fg}	39.49^{h}
	14	34.57^{e}	34.37^{e}	39.47^{f}	36.13^{g}
	28	31.67^{de}	30.87^{de}	34.62^{e}	32.38^{f}
	56	24.57^{cd}	23.68^{cd}	26.63^{cd}	24.96^{d}
Means^{1}		31.93^{e}	35.38^{f}	38.81^{g}	
200	1	34.40^{e}	58.20^{i}	59.17^{i}	50.59^{k}
	7	41.47^{fg}	48.73^{gh}	53.28^{h}	47.83^{j}
	14	37.67^{ef}	41.80^{fg}	48.53^{gh}	42.67^{i}
	28	36.07^{ef}	34.57^{e}	43.63^{fg}	38.09^{gh}
	56	29.08^{d}	29.20^{d}	34.87^{ef}	31.05^{f}
Means^{1}		35.74^{f}	42.50^{h}	47.90^{i}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 2.12, P.I/P.E/T = 4.73, P.E/T = 2.73] for Means^{1,2,3} respectively.

23. The effects of DMT-HFO extractions on the extracted total inorganic P (TOT-P_i) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.	s.s.	m.s.	F	F pr.
PHOSP (P)	4	915358.86	228839.72	3.98E+04	<.01
INC/PER (I/P)	2	3443.02	1721.51	299.36	<.01
EX/TIME (E/T)	4	17923.60	4480.90	779.21	<.01
PHOSP.INC/PER (P.I/P)	8	1455.68	181.96	31.64	<.01
PHOSP.EX/TIME (P.E/T)	16	1157.20	72.33	12.58	<.01
INC/PER.EX/TIME	8	1097.25	137.16	23.85	<.01
PHOSP.INCPER.EXTIME	32	2059.56	64.36	11.19	<.01
REPS	2	48.12	24.06	4.37	
Residual	150	862.58	5.75		
Total	224	943357.74			

SE = 2.40; CV = 1.3

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	113.2^{cd}	119.0^{de}	128.7^{ef}	120.3^{e}
	7	108.7^{c}	111.2^{cd}	117.2^{d}	112.4^{d}
	14	103.5^{bc}	104.5^{bc}	110.5^{c}	106.2^{c}
	28	99.3^{ab}	99.7^{ab}	104.2^{bc}	101.1^{b}
	56	93.8^{a}	93.3^{a}	100.6^{b}	95.9^{a}
Means^{1}		103.7^{a}	105.5^{a}	112.3^{b}	
25	1	145.3^{gh}	146.6^{gh}	156.1^{i}	149.3^{i}
	7	128.9^{ef}	137.8^{fg}	148.2^{h}	138.3^{h}
	14	127.0^{ef}	132.5^{f}	144.1^{gh}	134.5^{g}
	28	130.2^{ef}	129.5^{ef}	141.3^{g}	133.7^{g}
	56	125.0^{e}	124.5^{e}	131.9^{f}	127.1^{f}
Means^{1}		131.3^{c}	134.2^{c}	144.3^{d}	
50	1	171.8^{j}	178.7^{k}	192.3^{l}	180.9^{m}
	7	161.5^{i}	162.0^{i}	183.7^{k}	169.1^{l}
	14	156.0^{i}	161.9^{i}	170.8^{j}	162.9^{k}
	28	151.0^{hi}	148.4^{h}	157.9^{i}	152.4^{j}
	56	143.7^{gh}	149.2^{h}	154.5^{hi}	149.1^{i}
Means^{1}		156.8^{e}	160.0^{f}	171.8^{g}	

100	1	228.6^{q}	220.3^{pq}	229.6^{q}	226.2^{q}
	7	210.2^{np}	207.8^{n}	223.6^{q}	213.9^{p}
	14	202.4^{mn}	205.5^{mn}	210.9^{np}	206.3^{n}
	28	203.5^{mn}	208.1^{np}	208.4^{np}	206.7^{n}
	56	199.5^{m}	214.6^{p}	195.9^{lm}	203.3^{n}
Means[1]		208.8^{h}	$211.3g^{hi}$	213.7^{i}	
200	1	322.6^{u}	290.6^{s}	310.6^{t}	307.9^{t}
	7	289.6^{s}	281.8^{r}	293.7^{s}	288.4^{s}
	14	282.2^{r}	281.7^{r}	294.7^{s}	286.2^{s}
	28	281.3^{r}	283.0^{r}	283.5^{rs}	282.6^{r}
	56	282.2^{r}	277.9^{r}	280.8^{r}	280.3^{r}
Means[1]		291.6^{k}	283.0^{j}	292.7^{k}	

N.B. Means with the same superscripts are not significantly different (P = 0.001) LSD (Fisher) [P.I/P = 2.94, P.I/P.E/P = 6.57, P.E/T = 3.79] for Means[1,2,3] respectively.

24. The effects of DMT-HFO extractions on the extracted total soil P (TOT-P) of Loskop soil as influenced by added P and incubation period.

(i). Analysis of variance

Source of variation	d.f.(m.v.)	s.s.	m.s.	F	F pr.
PHOSP (P)	4	1.18E+06	2.95E+05	7.91E+04	<.01
INC/PER (I/P)	2	8.52E+03	4.26E+03	1142.21	<.01
EX/TIME (E/T)	4	4.35E+04	1.09E+04	2912.87	<.01
PHOSP.INC/PER (P.I/P)	8	1.20E+03	1.49E+02	40.07	<.01
PHOSP.EX/TIME (P.E/P)	16	1.78E+03	1.11E+02	29.81	<.01
INC/PER.EX/TIME (I/P.E/T)	8	1.43E+03	1.79E+02	48.00	<.01
PHOSP.INC/PER.EX/TIME	32	1.56E+03	4.86E+01	13.03	<.01
REPS	2	3.20E+01	1.60E+01	4.48	
Residual	149(1)	5.56E+02	3.73E+00		
Total	223(1)	1.23E+06			

SE = 1.93; CV = 0.9

(ii). Table of means

ADDED P (mg kg^{-1})	DMT-HFO EXTRACTIONS	INCUBATION PERIOD (DAYS)			
	Days	1^{2}	120^{2}	240^{2}	Means^{3}
0	1	136.5^{e}	139.5^{ef}	151.2^{g}	142.4^{e}
	7	127.0^{d}	125.8^{cd}	136.7^{e}	129.8^{d}
	14	122.7^{cd}	120.0^{bc}	127.4^{d}	123.4^{c}
	28	116.5^{bc}	115.0^{b}	120.6^{c}	117.4^{b}
	56	108.4^{a}	106.5^{a}	116.0^{bc}	110.3^{a}
Means^{1}		122.2^{a}	121.36^{a}	130.4^{b}	
25	1	171.2^{ij}	176.2^{j}	186.7^{kl}	178.1^{i}
	7	153.4^{g}	159.4^{h}	174.7^{j}	162.5^{g}
	14	148.3^{g}	151.8^{g}	167.3^{i}	155.8^{f}
	28	150.3^{g}	148.3^{g}	161.8^{h}	153.5^{f}
	56	142.7^{f}	140.0^{ef}	150.7^{g}	144.5^{e}
Means^{1}		153.2^{c}	155.2^{c}	168.2^{d}	
50	1	199.8^{m}	218.4^{n}	236.6^{q}	218.3^{l}
	7	192.4^{l}	190.2^{l}	220.0^{np}	200.9^{k}
	14	184.5^{k}	186.6^{kl}	203.0^{m}	191.3^{j}
	28	175.4^{j}	169.7^{ij}	186.5^{kl}	177.2^{i}
	56	163.5^{hi}	167.5^{i}	177.0^{j}	169.3^{h}
Means^{1}		183.1^{e}	186.5^{f}	204.6^{g}	
100	1	260.6^{t}	270.4^{u}	279.3^{v}	270.1^{r}
	7	247.1^{rs}	245.8^{rs}	267.3^{u}	253.4^{q}
	14	237.0^{q}	239.9^{qr}	250.4^{s}	242.4^{p}
	28	235.1^{q}	239.0^{qr}	242.4^{r}	238.8^{n}
	56	224.0^{p}	238.3^{qr}	222.6^{np}	228.3^{m}
Means^{1}		240.8^{h}	246.6^{i}	252.4^{j}	
200	1	357.0^{C}	348.8^{B}	369.7^{D}	358.5^{w}
	7	331.0^{z}	330.6^{z}	347.0^{AB}	336.2^{v}
	14	319.8^{xy}	323.5^{y}	343.2^{A}	328.9^{u}
	28	317.4^{x}	317.6^{x}	327.2^{yz}	320.7^{t}
	56	311.3^{wx}	307.1^{w}	315.3^{x}	311.2^{s}
Means^{1}		327.3^{k}	325.5^{k}	340.5^{l}	

N.B. Means with the same superscripts are not significantly different ($P = 0.01$) LSD (Fisher) [P.I/P = 2.37, P.I/P.E/T = 5.29, P.E/T = 3.06] for Means^{1,2,3} respectively.

25. A copy of Genstat 5 Release 4.1 computer programme used in the statistical analysis of Rustenburg and Loskop soils data.

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Genstat 5  Release 4.1  (PC/Windows 95)                  18 May 2001 16:00:50
Copyright 1997, Lawes Agricultural Trust (Rothamsted Experimental Station)
    1  JOB 'PHOSPHORUS BINDING IN RUSTENBURG RED CLAY'
   2  "ON NETWORK H:\HOME\VICTOR as XRUST2.DAT; XRUST2.OUT"
   3  UNITS [NVALUES=225]
   4  FACTOR [LEVEL=5;LABEL=!T('0','25','50','100','200')] PHOSP
   5  FACTOR [LEVEL=3;LABEL=!T('0','120','240')] INCPER
   6  FACTOR [LEVELS=5;LABEL=!T(DAY1,DAY7,DAY14,DAY28,DAY56)] EXTIME
   7  FACTOR [LEVELS=3] REPS
   8  OPEN 'A:XRUST2.DAT';WIDTH=160;FILETYPE=INPUT;CHAN=4
   9                                                             READ[CHAN=4]
BOT,PHOSP,REPS,INCPER,EXTIME,HFOPi,HCOPi,OHPi,DHClPi,CHClPi,HSOPi,\
  10                 HCOPt,OHPt,CHClPt,HCOPo,OHPo,CHClPo,TOTPo,TOTPi,TOTP
    Identifier   Minimum      Mean   Maximum    Values   Missing
           BOT       1.0     113.0     225.0       225         0
         HFOPi      2.00     24.56     91.60       225         0
         HCOPi      1.50     12.97     70.50       225         0
          OHPi      8.50     51.62    106.70       225         0
        DHClPi      4.00     12.50     30.80       225         0
        CHClPi     34.00     53.88     91.80       225         0
         HSOPi     35.25     59.01     99.25       225         0
         HCOPt      5.00     22.78     86.00       225         0
          OHPt     16.00     68.21    140.20       225         0
        CHClPt     41.00     64.54    112.00       225         0
         HCOPo     2.800     9.804    23.900       225         0
          OHPo      5.60     16.59     34.60       225         0
        CHClPo      5.00     10.66     21.00       225         0
         TOTPo     16.85     37.00     74.80       225         1
         TOTPi     101.7     214.0     352.5       225         1
          TOTP     124.5     251.6     424.6       225         0
    Identifier    Values   Missing    Levels
         PHOSP       225         0         5
          REPS       225         0         3
        INCPER       225         0         3
        EXTIME       225         0         5
  11  BLOCK REPS.PHOSP.INCPER.EXTIME
  12  TREAT PHOSP*INCPER*EXTIME
  13  FOR Y=HFOPi,HCOPi,OHPi,DHClPi,CHClPi,HSOPi,OHPt,CHClPt,\
  14        HCOPt,HCOPo,OHPo,CHClPo,TOTPo,TOTPi,TOTP
  15  ANOVA [PRINT=AOVTABLE,INFO,MEANS,%CV;FPROB=YES;PSE=LSD,MEAN] Y;\
  16                             RESIDUALS=RES;FITTEDVALUES=FIT
  17  TABULATE [CLASS=PHOSP,INCPER,EXTIME] Y; MEANS=MTAB
  18  PRINT MTAB; FIELD=10; DECI=2
  19  TABULATE [PRINT=MEAN;CLASS=PHOSP,EXTIME,INCPER] Y
  20  CALC ST_RES=RES/(SQRT(VAR(RES)))
  21  GRAPH [NROWS=10;NCOL=25] ST_RES;FIT
  22  HIST ST_RES
  23  PRINT 'TEST FOR NORMALITY'
  24  NORMTEST [PRINT=m,s,c] ST_RES
  25  PRINT 'TEST HOMOGENEITY OF PHOSPHATE LEVELS'
  26  VHOMOGENITY [GROUPS=PHOSP] Y
  27  PRINT 'TEST HOMOGENEITY OF EXTIME'
  28  VHOMOGENITY [GROUPS=EXTIME] Y
  29  PRINT 'TEST HOMOGENEITY OF INCPER'
  30  VHOMOGENITY [GROUPS=INCPER] Y
  31                                                                    PRINT
BOT,PHOSP,REPS,INCPER,EXTIME,Y,FIT,ST_RES;DECI=5(0),3(3);FIELD=10
  32  ENDFOR
```