AFRICA UNIVERSITY

EFFECT OF CROP SEQUENCING ON EFFECTIVENESS OF DOROWA PHOSPHATE ROCK AS A SOURCE OF PHOSPHORUS

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION

FACULTY OF AGRICULTURE AND NATURAL RESOURCES

BY

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DECLARATION

I, Itai Blessings Mutukwa, do hereby declare that this dissertation is my original work undertaken at Africa University, Mutare, Zimbabwe, under the supervision of Professor F. Tagwira and Dr, Z.A. Chiteka in partial fulfillment of the requirements for the degree of Master Science in Crop Production Degree. References cited in this study and sources of data have been fully acknowledged. This work has not been previously accepted for any degree and is not being currently submitted in award for any other degree.

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ABSTRACT

Declining soil fertility remains the fundamental cause for the reduction in per capita food production in Sub-Saharan Africa, N and P being the most limiting nutrient elements. In Zimbabwe, there is a decline in soil fertility, as farmers take out more nutrients than they apply. While soil N status can be improved through several means such as biological fixation, P has to be added. Soil fertility needs in Zimbabwe have traditionally been partially met from the use of cattle manure in the communal areas. Besides being scarce due to the declining cattle herd, communal area manure is a poor source of P. Zimbabwe has large deposits of the inexpensive granite derived Dorowa Phosphate Rock (DPR). However, it has low solubility thus unsuitable for direct application. The aim of this research was to test the potential of various crops to solubilize P from DPR for a subsequent maize crop. Among these crops are legumes which could also contribute soil nitrogen through biological nitrogen fixation.

An experiment was conducted in the greenhouse and at two field sites. Treatments consisted of five fertilizer rates (0, 40, 80, 120kg/ha P_2O_5 as DPR and 80 kg/ha P_2O_5 as DSP) and five initial crops (cow peas, groundnuts, pigeon peas, sugar beans and rapeseed) combined factorially (5*5) to give a total of 25 treatment combinations. The experiment was laid out as a randomized complete block design with three replicates. After growing for 6 weeks the initial crops were harvested and the residues were incorporated into the soil except for rapeseed. The residues were left to decompose for 120 and 14 days in the greenhouse and field experiments respectively. After this, maize was grown in the same soil using the residual P from applications made to the initial crop. The greenhouse and field experiments were then used to assess the potential of crop sequencing in enhancing P availability from DPR for a following maize crop.

Results on P analysis showed an increase in soil available P_2O_5 with increase in DPR rate. Available P_2O_5 after harvest of the initial crops was higher where P had been applied as DSP when compared to DPR. Amount of available P_2O_5 after the different initial crops had been harvested varied significantly indicating that the crops vary in their potential to help solubilise DPR. Rhizosphere pH after growth of the initial crops was lower where the legumes had been grown when compared with rapeseed. Maize biomass was higher where P had been applied as DPR when compared with DSP application. Results on maize biomass showed higher RAE of DPR with respect to DSP when compared to results on soil available P_2O_5 after the initial crops were harvested. Results showed no maize grain yield response to the different applied P fertilizer rates. The interaction of DPR rates and different initial crops resulted in significant differences in maize biomass yield. Maize biomass yield was higher were groundnuts had been previously grown in combination with DPR as compared to the other initial crops.

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1.0 INTRODUCTION

Crop yield on 40% of the world's arable land is limited by phosphorus (P) availability. Phosphorus is second only to nitrogen (N) as the most limiting element for plant growth (Vance, 2001). The highly weathered soils of the tropics and subtropics are particularly prone to P deficiency and aluminum (Al) toxicity (von Uexküll and Mutert, 1995). Declining soil fertility remains the fundamental root cause for the reduction in per capita food production in Sub-Saharan Africa. In Zimbabwe, there is a decline in soil fertility, as farmers take out more nutrients than they apply (Chibudu, Chiota, Kandrios, Mavendzenge, Mombeshora, Mudhara, Murimbarimba, Nasasara, and Scoones, 2001). Most of Zimbabwe's soil is derived from course-grained granite, acidic and inherently infertile (Chikowo, 1998). While soil fertility needs have traditionally been partially met from the use of cattle manure in the communal areas (Chikowo, 1998), communal area manure appears to be a poor source of P thus insufficient to meet the requirements for sustained crop production (Chikowo, Tagwira and Piha, 1999; Tanner and Mugwira, 1984).

The amount of P in plants ranges from 0.05% to 0.30% of total dry weight and the concentration gradient from the soil solution to the plant cell exceeds 2000-fold, with an average free P of 1 μM in the soil solution (Schachtman, Reid, and Ayling, 1998). This concentration is well below that required for plant uptake, thus, although bound P can be abundant in many soils, it is largely unavailable for uptake (Schachtman *et al.*, 1998).

While N needs can be met realistically through biological nitrogen fixation where crop residues and animal manure are returned to the field, P can only come from external input. Inorganic fertilizer, manure and phosphate rocks are the major sources of P. Manure is now very limited in the smallholder farming sector because of declining livestock herd, while phosphate fertilizer is expensive and out of the reach of most smallholder farmers. On the other hand, Zimbabwe has large deposits of the granite derived Dorowa Phosphate Rock (DPR). The phosphate rock is however too insoluble for direct application and is only used for production of superphosphates. Production of superphosphates is essentially a process of solubilizing P ores obtained from mining operations and both mining and solubilizing require a high energy input (White and Johnson, 1980) thus making soluble phosphate fertilizer expensive.

Dorowa Phosphate Rock has been shown to be inexpensive and to have long term residual effects that can contribute to recapitalization of P in soils however, if directly applied it does not produce the desired short-term outcomes due to its low P solubility (Govere, Chien and Fox, 2005; Dhliwayo, 1999). To produce short term benefits it must be modified. Dorowa phosphate rock is an inexpensive source of P and there is need to enhance its P solubility so as to increase its agronomic effectiveness when applied directly.

Techniques to enhance PR solubility that have been investigated include; heap leaching, thermal treatment, mechanical activation, modification through biological processes, use of chemo-physical means like partially acidulating PRs, reacting with synthetic organic acids and or natural organic acids, and decreasing particle size (Goenadi, 1990; Govere, Chien and Fox 2005). Compositing of PRs with agricultural wastes has been shown to increase solubility of PRs (Bangar, Yadav, Mishra, 1985 and Mishra and Banger, 1986). The P solubility of a given rock phosphate varies with the kind of organic material and the rate of decomposition (Bangar *et al*, 1985). In Zimbabwe, agronomic effectiveness of DPR has been shown to increase when composted with cattle manure (Dhliwayo, 1999).

The usefulness of various PRs with different degrees of solubility may vary with the crop species (Chien, Sale, and Hammond, 1990). One crop may be better at improving PR dissolution than another and thus a following crop may benefit from P released from PR by the first crop. Crop factors such as P demand, calcium absorption, exudation of acidic compounsds to the rhizosphere, rooting density and type of growth cycle are all known to influence agronomic efficiency of phosphate rock in crop plants (Chien *et al.*, 1990). Annual legumes have been shown to use PR very efficiently (Bekele, Cino, Ehlert, Van Der Mass, and Van Diest, 1983) through their excretion of hydrogen ions which acidifies the rhizosphere and allows for increased PR dissolution (Chien, 1979). Other crops like cabbage and rapeseed have been shown to enhance P availability by excretion of citric and malic acids (Hoffland, Findengg and Nelemans, 1989). Plant microbial associations may also increase agronomic effectiveness of PRs. Vescicular arbuscular mycorrhizae (VAM) infection can provide intimate contact and make more efficient use of insoluble PR (Sieverding and Golvez, 1988) while phosphate solubilising bacteria may also enhance P availability from PRs (Shehana and Abraham, 2001) .

As observed with other PRs, it is possible that certain crop sequences may help increase DPR dissolution, therefore improving P availability for the subsequent crop (van Straaten, 2002). If the first crop, which increases solubility, is a legume then a double benefit is derived as it will also improve N availability for the following non legume crop.

Maize is the staple food in Zimbabwe and yet yields are declining due to decline in soil fertility. The aim of this research was to test the potential of various crops (which have been shown to enhance P dissolution) to solubilize P from DPR for the subsequent maize crop. Among these crops are legumes which could also contribute to soil nitrogen through biological nitrogen fixation.

1.2 OBJECTIVE

To increase maize productivity in the small holder sector through improved utilization of DPR

1.2.2 Specific objective

To assess the effect of varying crop species fertilized with DPR on increasing P availability for the subsequent maize crop.

1.3 HYPOTHESIS

(Mention the crops here)

Certain crops can improve P availability from DPR for a subsequent crop in a cropping sequence, because of ???

2.0 LITERATURE REVIEW

2.1 SOIL FERTILITY STATUS OF ZIMBABWE'S SMALL HOLDER FARMING SECTOR

Residents on smallholder farms comprise 70% of Zimbabwe's population and the majority of them struggle to meet their food requirements, (Mudhara, Hildebrand and Galdwin, 2003). In Zimbabwe, the major constraints to crop production in the smallholder sector include low nutrient availability, soil acidity and low moisture content, (Tagwira, 2001). More than 60% of Zimbabwe's soil is derived from course-grained granites, (Chikowo, 1998). These soils have low cation exchange capacity (about 2-4 me/100g soil), often markedly acidic (pH of 4.5 in 0.01M $CaCl_2$) especially in the subsoil, low in mineral fertility and unfortunately occupy the majority of agricultural lands especially in the communal areas where the majority of smallholder farmers are located (Chikowo, 1998). The weak soil structure that is characteristic of sandy soils makes them prone to erosion and nutrient losses (ICRAF-SA, 2007). While soil fertility has in general been identified as the constraint to crop productivity, these soils are notably deficient in N and P (ICRAF-SA, 2007).

In Zimbabwe, there is a decline in soil fertility as farmers take out more nutrients than they apply (Chibudu *et a*l., 2001). Small holder farmers have not adopted the higher levels of fertilizer applications recommended to them, as they are not achievable with the limited resources at their disposal for agricultural production, (Mudhara *et al.*, 2003). Soil fertility needs have traditionally been partially met from the use of cattle manure in the communal areas (Chikowo, 1998), but this communal area manure is of low quality and is a poor source of P (Tanner and Mugwira, 1984). The low level of P in the manure is caused by poor pastures on which the animals graze.

2.2 DOROWA PHOSPHATE ROCK CHARACTERIZATION

All of the known phosphate resources in Zimbabwe are either of igneous provenance, associated with carbonatites or guano. In Zimbabwe bat guano is not considerered a mineral under the mines and minerals act. Barber (1991) considered it a potential source of possibly inferior but still highly beneficial phosphate rich fertilizer suitable for direct application. There are several caves with bat guano in Zimbabwe, the majority of which are found in the Lomagundi dolomitic marbles and limestones (van Straaten, 2002).

Zimbabwe has phosphate reserves amounting to 37 million Mg at Dorowa in Manicaland Province and 18 million Mg at Shamva in Mashonaland Central as well as a considerable amount at Chishanya, (Mc Clellan and Notholt, 1986). From the four Mesozoic carbonatites available in Zimbabwe, (Dorowa, Shamva, Chishanya, and Katete), only the Dorowa deposit is mined for phosphates at present, (van Straaten, 2002). There are no known sedimentary phosphates in the country (van Straaten, 2002).

Fernandes and the International Fertilizer Development Center (IFDC) (1978), carried out detailed mineralogical investigations on phosphate samples from Dorowa and the apatite was identified as hydroxy-fluor-apatite with a low neutral ammonium citrate soluble P of 0.8% P_2O_5. Dorowa phosphate rock (DPR) has an approximate composition of Ca_{10} $(PO_4)6(F_{1.08}$, $OH_{0.92})$ and it is a hydroxyl –flourapatite with MgO/ P_2O_5, CaO/ P_2O_5, $(Fe_2O_3 +Ai_2O_3)/ P_2O_5$

and Fe_2O_3 +Al_2O_3 + MgO)/P_2O_5 weight cations, which is suitable for the production of conventional phosphorus fertilizers such as single super phosphate (SSP) and triple super phosphate (TSP), (Roy and McClellan, 1985).

2.3 SOIL PROPERTIES AFFECTING CROP RESPONSE TO PR FERTILIZERS

The soil properties that have the greatest influence on the relative agronomic effectiveness (RAE) of PR are soil pH, exchangeable Ca^{2+}, soil texture (or cation exchange capacity) and P sorption capacity (Chien, 1979).

2.3.1 Soil pH

Soil pH affects availability of applied P by influencing the nature of ensuing P reactions and thereby the reaction products formed. Generally, P availability is greatest in soil pH range of 5.5-7.0 (Engelstad and Terman, 1980). No PR source is effective on soils having pH levels above 5.5-6.0 (White and Johnson, 1980). In a study done using various PRs and rice as the test crop by Englestad, Jugsujinda, and De Datta (1974), pH had little effect on rice response to TSP; however, the effectiveness of PRs greatly depended on soil pH. In that research, at pH of 4.6 the flooded rice responded to PRs, with the degree of response depending on the PR's reactivity while at pH of 8, all PR's were ineffective. Soil pH can also affect the growth of plant root systems and their ability to take up P which has practical implications for the utilization of both soil and applied P (Engelstad and Terman, 1980).

2.3.2 Exchangeable calcium and cation exchange capacity

Phosphate rock dissolution releases calcium (Ca^{2+}) ions thus soils with a high Ca^{2+} content slow down the dissolution of PR (Chien, 2001) according to the mass action law (Hammond, Chien, and Mokwunye, 1986). Therefore, crop species with a high uptake of Ca^{2+} such as groundnuts, will increase rate of PR dissolution in the soil. Flach, Quak and van Diest (1987) reported that the mobilizing capacity of three cereal crops on several PRs in increased order is, maize< pearl millet< finger millet and this was attributed to a comparatively higher Ca^{2+} uptake by finger millet. The P concentration in solution should increase as the Ca^{2+} concentration decreases, thus on the basis of the solubility-product principle for PR dissolution, the concentration of P in solution should be greatest in the presence of plants that absorb the most Ca^{2+} (Black, 1968). The formation of extensive root hairs in some plants such as cabbage encourage uptake of high amounts of Ca^{2+} (Hoffland *et al.*, 1989). Crops with a high calcium demand and uptake include sweet clover and groundnuts thus growing such crops where there is direct application of PR's could help increase P solubility from PR's. However, for many tropical acid soils, exchangeable Ca^{2+} is relatively low, thus providing favourable conditions for PR dissolution (Chien, 2001).

Soil cation exchange capacity (CEC) is closely related to Ca^{2+} in its effect on PR agronomic effectiveness (AE). Sandy soils with low CEC do not provide a sink for Ca^{2+} ions released in PR dissolution hence the PR dissolution is slowed, which may result in a reduction in relative agronomic effectiveness (RAE), (Kanabo and Gikes, 1988).

2.3.3 P sorption

Soils with high P sorption tend to give low RAE of PRs. Harris (1985) reported that a PR of medium reactivity when compared to SSP or TSP had higher RAE in an acid soil with low P sorption capacity than in a soil with higher P sorption capacity. As P sorption capacity increases, P initially available from PR directly applied may decrease more rapidly than will that from soluble P sources despite the fact that decomposition of PR increases with increase in soil P sorption capacity, (Chien, 2001). However, the possible negative effect of soil P fixing capacity on RAE of PR with respect to water soluble P applies to the initial P effect but for residual P effect, RAE of PR tends to increase as soil P fixing capacity increases (Chien, 2001).

2.4 CROP CHARACTERISTICS AFFECTING CROP RESPONSE TO PR FERTILIZERS

According to Chien (2001), the usefulness of PR varies with crop species.

2.4.1 Length of growing season

The RAE of PR's is generally higher in long term perennial crops than in short term or annual crops (Chien, 2001) and this is the reason why use of PR is common for pastoral crops in Brazil and Chile, and for tree crops such as rubber and oil palm in Asia.

2.4.2 P demand

The RAE of PRs varies with P demand by the crop. Relative agronomic efficiency is higher in crops with a lower demand of high P concentration in soil solution, such as legumes, as compared to cereals (Chien, 2001). Khasawneh and Sample (1979) suggested that the concentration of soil P required by cowpea for maximum growth potential may be two thirds that of maize thus RAE would be higher for cowpeas than for maize. Direct application of PR is thus recommended largely in rotations involving legumes (Adams, 1980).

2.4.3 Rhizosphere processes

Through various chemical modifications plant roots induce in the rhizosphere, higher plants may also be directly responsible for dissolution of PR (Hinsinger and Gikes, 1997). The rate of P solubilization is directly correlated with decrease in pH of the medium (Singh and Ambeger, 1998), thus the acidification of the plant's rhizosphere can also account for differences in PR dissolution (Chien, 2001). The dissolution of PR in acidic pH conditions can be described by the following equation for flour apatite (Khasawneh and Doll, 1978):

$$Ca_{10}(PO_4)_6F_2 + 12H^- \Leftrightarrow 10Ca^{2+} + 6H_2PO_4- + 2F^-$$

From this equation, the dissolution of PR may be enhanced by the supply of protons and or the removal of dissolution products, in particular Ca^{2+} and P ions. According to Hinsinger and Gikes (1995), the input of protons excreted by plant roots into the soil can lead to significant decrease in soil pH, particularly in poorly buffered soils. Van Ray and Van Diest (1979) used

Gaftsa PR from Tunisia on different plant species; paspalum grass, maize, molasses grass, soybean and buckwheat and found that the PR was as good as TSP for buckwheat which produced a lower soil pH than did the other plant species through the imbalance of cation absorption by the roots.

Legumes have been shown to increase the dissolution and utilisation of P from PR compared with non-legumes, mainly due to rhizosphere processes (McLenaghen, Randhawa, Condron and Di, 2004). Diverse species which include buckwheat, oilseed rape, white lupin and narrow lupin have been known to induce PR dissolution through excretion of protons that acidify the soil (Hinsinger and Gikes, 1995). White Lupin's adaptation to P stress is through modification of root development and biochemistry resulting in cluster roots that exude copious amounts of organic acids such as citrate and malate, and acid phosphatase (Vance, 2001). The roots of the leguminous pigeon pea (*Cajanus cajan*) release piscidic acid that can enhance the availability of iron-bound phosphorus (van Straaten, 2002).

Hinsinger and Gikes (1997) studied the dissolution of PR in the presence and absence of plants grown in an acid mineral substrate which stimulates P fixation and was devoid of Ca^{2+} and P with PR being the only P and Ca^{2+} source. The plants used were oilseed rape, annual rye grass, subterranean clover and tomato. More dissolution was observed in the presence of plant roots as indicated by a significant decrease in total Ca^{2+} content in the PR amended substrate and a simultaneous accumulation of dissolved P in the rhizosphere and plant material of the five plant species. In this experiment, the largest root induced dissolution was achieved by rye grass and rapeseed.

Exudation of malic and citric acids by rapeseed roots is thought to be responsible for PR dissolution (Hoffland et al., 1989). Hinsinger and Gikes (1997) also reported that rape seed increases P dissolution and this is mainly attributed to excretion of organic acids by the roots. Habib, Chien, Carmona and Henao (1999) found a medium reactive Syrian PR to be 58 % of triple super phosphate for rapeseed grown on an alkaline soil with pH 7.8. For plants that exude citrate like rapeseed, PR dissolution can be enhanced through the formation of the precipitate Ca-citrate in the rhizosphere and thus citrate thereby acts as a sink for Ca^{2+}.

Subsequent or intercropped crops can thus benefit from the increased availability of phosphorus through crops that enhance P availability from PR through rhizosphere processes (van Straaten, 2002).

2.4.4 Rooting density

Crop rooting density has been shown to affect AE of directly applied phosphate rock. Chien *et al.* (1990) conducted research on the effectiveness of Sechura PR from Peru relative to TSP on a Mountview silt loam (pH 4.8) with five different crops. The Sechura PR was less effective than TSP for wheat, maize and flooded rice but was as good as TSP for upland rice and rye grass. The efficient use of PR by rye grass was probably due to its high rooting density. Present views tend to stress the great importance of root morphology for P uptake (Tinker, 1980). According to autoradiographs of depleted zones around roots (Lewis and Quirk, 1967; Bhat and Nye, 1974) and by calculated P concentration gradients necessary to provide observed fluxes of P into the roots (Bar Yosef, Brewster and Kafkafi, 1972; Brewster, Bhat, and Nye, 1975; Mengel and Barber, 1974), diffusion is nearly always a major rate limiting step in P uptake from the soil (Tinker, 1980). Root hairs help to circumvent this problem since they absorb P from the soil between them and in effect also give roots a larger radius, whereby the maximum theoretical uptake is increased (Nye, 1966). If a crop is grown after one that has higher P uptake from PR due to its high rooting density and its residues incorporated back into the field, the succeeding crop has potential to benefit from the P mobilized by the preceding crop.

2.5 ASSOCIATION WITH MICROORGANISMS AS IT AFFECTS CROP RESPONSE TO PR FERTILIZERS

It is suggested that microorganisms could potentially alter P uptake rates from PR. According to Tinker (1980), mechanisms by which microorganisms could potentially alter P uptake rates seem to be: alteration of root morphology, in particular root hair length and density or change of active root length; change of mean absorbing power of the root over all or part of its surface; displacement of sorption equilibrium to produce higher local P concentrations in the soil solutions, thereby allowing a higher flux toward the root surface and a higher uptake rate and facilitated transport of P to the root, again allowing larger uptake rate and possibly from a larger soil volume and sparingly soluble P sources such as PRs.

Mycorhizae are close, stable and permanent associations of roots of a higher plant and mycorrhiza fungi where no apparent damage results to either partner though there may be morphological changes (Tinker, 1980). The type of mycorrhizae that improves P uptake by plants is vescicular-arbuscular mycorrhizae (VAM), and the commonly used spore producing types are *Glomus fasciculatum*, *G. mosseae*, *G. etunicatum*, *G. tenue* and *Giaspora margarita* (FAO, 2004). VAM fungi infect the cells of the root cortex and form both an internal network of hyphae and an external growth of hyphae (FAO, 2004). They possess special structures known as vesicles and arbuscules which are highly branched and help in the transfer of nutrients from the fungus to the plant-root cells, and the vesicles are sac-like structures, which store P as phospholipids (FAO, 2004).

Enhanced P uptake in VAM-infected plants seems to be facilitated by: (i) the fungal hyphae exploring a greater volume of soil for P and also intercepting a greater number of point sources of P (ii) the fungi dissolving sparingly soluble P minerals like PR and (iii) the infected roots increasing the rate of P uptake, by increasing the diffusion gradient by depleting P to lower P concentrations than can non-mycorrhizal roots and by enhancing the transfer of P between living roots and from dying roots to living roots (Bolan and Robson, 1987; Sylvia, 1992; Frossard, Brossard, Hedley and Metherell, 1995; Lange Ness and Vlek, 2000). The P inflow rates of mycorrhizal roots are calculated to be 2-6 times those of non-mycorrhizal roots (Jones, Duraqill and Tinker, 1998).

Results of work done by Hayman and Mosse (1972) suggest that mycorrhiza do not render wholly unavailable sources of P useful but that they can accelerate the uptake rate from low solubility sources. Azcon, Barca, and Hayman (1975), reported that lavender plants responded to PR only after infection with mycorrhizae. However, several comparisons in pots on the effects of PR on legume crops with and without mycorrhizae in a range of soils confirmed that VAM could improve but not confer the ability to use PR efficiently (Mosse, 1977). Research done on several plants using tricalcium phosphate (TCP), hydroxyl apatite, PRs and other calcium phosphates showed that mycorhizal plants were much larger than non-mycorrhizal plants with TCP, less with PR and least for the more insoluble dicalcium phosphates (Daft and Nicolson, 1966). Inclusion of a crop with strong VAM association in a rotation where there is direct application of PR could enhance agronomic effectiveness of the PR for the crop and if its residues are turned in after harvest or as green manure, the succeeding crop could also benefit.

Some bacteria have also been known to solubilise P from PR thus increasing P availability to plants. Direct application of phosphate rock in conjunction with phosphate solubilising bacteria resulted in an increase in P availability from 12 to 21% and a subsequent improvement in nutrient uptake in the presence of phosphate solubilising bacteria compared to the control (Supanjani, Han, Jung and Lee, 2006).

The effect of phosphobacteria, a mixed culture of P solubilising bacteria and fungi on the maintenance of available P status in soil was monitored by carrying out an incubation study in the laboratory (Shehana and Abraham, 2001). Results showed that incubation of the soil with the P solubilising organisms brought into solution more P from the soil at the end of 90 days compared to the untreated control (Shehana and Abraham, 2001).

Association with microorganisms that solubilise bound phosphate is not equally common to all plants. Most plants (more than 90% of all known species) present at least one type of mycorrhiza, while the cruciferae family in general and some aquatic plants are usually non-mycorrhizal (Muchovej, 2001). Amongst plants with mycorrhizal associations, the fungal strains vary and so does the extent of their effectiveness in availing P from PR's to plants. Similarly, activity of phosphate solubilising bacteria is not equal in all plants. Ponmurugan and Gopi (2006) conducted an experiment to enumerate the population density of phosphobacteria in the rhizosphere of brinjal, chilly, cotton, green grain, groundnut, maize, paddy rice, ragi, sorghum and turmeric using the Ketznelson and Bose medium following the dilution plate technique. The results showed that the population levels of phosphobacteria were higher in the rhizosphere of groundnut plants. Results on the phosphatase enzyme activity on TCP showed that the strain GP02 which was isolated from the groundnut rhizosphere soil had higher activity followed by the strain SP03 isolated from the sorghum rhizosphere. However, there was a positive correlation between phosphate solubilising capacity and phosphatase enzyme activity.

2.6 MANAGEMENT FACTORS AFFECTING CROP RESPONSE TO PR FERTILIZERS

2.6.1 Application Method

The application method affects agronomic effectiveness of PR's. According to Englestad and Terman (1980), when applying phosphates of low solubility such as done in direct PR application, broadcast followed by incorporation is the most effective method which encourages a higher dissolution rate. In a study by Chien (2001), North Carolina PR, when broadcast and incorporated, was found to be as good as TSP in increasing rice grain yield whereas it was less effective than TSP when deeply placed. Broadcasting of PRs followed by incorporation maximizes the surface contact of PR particles with the soil and minimizes interaction between PR particles (Chien, 2001).

2.6.2 Organic matter

The amount of organic matter in the soil affects AE of PRs. Decomposing organic matter generally produces organic acids that can enhance PR dissolution (Van Straaten, 2002). Microorganisms involved in decomposition require P nutrition for growth thus inorganic P is converted into the organic form of P and upon death and decomposition of the decomposers, this organic P pool is converted to plant available P (van Straaten, 2002). Calcium chelation by organic functional groups or anions supplied during composting can also contribute to PR dissolution (Singh and Amberger, 1990).

In work done by Chien (1979) on two soils of different organic matter (OM) content, Hartsels (4.2% OM) and Mountview (1.8% OM), the better performance of PR with respect to TSP in the Hartsels was attributed to the formation of a complex between organic matter and calcium which would enhance PR dissolution. In using PR's as sources of P, practices that increase soil organic matter increase agronomic effectiveness of PR's. These practices include crop rotation, adding of organic manure to the field as well as turning in crop residues after harvest of crops. However, with expanded use of crop residues as forage for the animals, annual soil P replenishment from crop residues is less than in the past (Hanway and Olson, 1980).

The amount of P removed by an average yield of harvested grain varies from 7-17 kg/ha of P as shown in Table 2.1 which amounts to 16-34 kg P_2O_5 with from 2 to 8 kg/ha taken up by the plants but returned to the soil in the event that crop residues are left in the field (Hanway and Olson, 1980).

Table 2.1. Amount of P removed from the soil at harvest of different crops

Crop		Grain yield (kg/ha)	P content (kg/ha)	
			Grain	Plant less grain
Corn		5000	15	6
Sorghum		4000	10	6
Soybeans		1800	13	2(+ 4 in leaf fall)
Small grains	Wheat	2400	9	2
	Oats	1600	7	4
	Barley	1900	7	2

(*Adapted from Hanway and Olson, 1980*)

The decomposition of plant residues in soil results in the production of numerous organic acids, such as oxalic, citric and tartaric acids (FAO, 2004). These acids can be expected to dissolve PR by supplying the hydrogen ions needed to neutralize the hydroxyl ions produced when PR dissolves and by forming complexes with cations, especially the Ca^{2+} from PRs (FAO, 2004). The organic ions and humus can also reduce the P sorption capacity of soils by blocking P sorption sites and by forming complexes with iron and aluminium hydrous oxides, leading to increased P concentration in solution (Manickam, 1993).

The incorporation of legumes as green manure in cropping systems may improve the utilisation of PR and therefore influence the dynamics and availability of P (McLenaghen *et al.*, 2004). A promising agronomic approach in organic cropping systems appears to be the integration of legume green manures into the cropping rotation, which can mobilize P from sparingly soluble PR or fractions that are not available to the following crop (Horst, Kamh, Jibrin and Chude, 2001). It is suggested that a legume green manure can be used to enhance P cycling by modifying the distribution and availability of PR and that this might have beneficial consequences for the following crop (McLenaghen et al., 2004). If green manures are turned in on decomposition, they liberate their P in the soil and accumulate organic acids which interact with soil complexes to affect the P availability through different mechanisms. Organic acids produced due to green manure decomposition complex metal cations; Ca^{2+}, Al^{3+} and Fe^{3+}, thereby helping in solubilizing of soil native P and reduction in P sorption (Dinesh, Duby and Nair, 1999).

McLenaghen *et al.* (2004) conducted a field experiment over two years to study the combined effect of legume growth (in terms of improved P utilization from PR) and its subsequent incorporation as a green manure on the test crop in comparison to a corresponding winter fallow system. Lupin (*Lupinus angustifolius, cv.* Fest) was grown as a green manure and maize (*Zea mays, cv* Elita) as a test crop. They concluded that lupin as a green manure winter crop in combination with PR can enhance P nutrition of the subsequent maize crop due to the capacity of lupin to solubilise the sparingly soluble (reactive) PR. These increases in maize performance clearly reflected the earlier observed responses of the green manure lupins to PR addition. Enhanced P uptake by maize in green manure-PR combinations compared with fallow-PR also indicate processes operating in the lupin rhizosphere that result in better utilisation of PR and the subsequent effect of lupin organic matter additions on the increased solubilization of residual PR (McLenaghen *et al.*, 2004).

2.6.3 Phosphate rock residual effect and crop sequencing

Phosphorous, more than N, has residual effect that lasts over several seasons based on soil type, crop yields and agro-climate (Singh, Fofana, Breman, van Reuler, Vanlauwe and Chien, 2001). In a study done in Togo, the residual effect of Togo PR and single super phosphate (SSP) was compared at two sites with maize used as the test crop. While maize yields with annual applications of PR were significantly lower at both sites than SSP, performance of Togo PR was better as residual fertilizer than as freshly applied (Singh *et al.*, 2001).

A study was done to compare P utilization from North Carolina phosphate rock (NCPR), China phosphate rock (CPR) and TSP, using three consecutive croppings of maize on Serdand series (Typic Paleudeult) (Zahara, Sharifuddin, and Sahali, 1997). The results showed that NCPR was as good as TSP in providing P to the first crop, while CPR showed the lowest percentage of utilization (Zahara et al., 1997). However, for the second crop, NCPR was better than the other P sources. In contrast, the third crop showed very poor percentages of P utilization for all the P sources.

Ng (1993) conducted an experiment to evaluate the effectiveness of NCPR, CPR, and Jordainian phosphate rock (JPR) with TSP as a control, on maize grown after Muccuna to which PRs had been added. The residual P effect was strongest in the treatment where Muccuna was grown in conjunction with NCPR and JPR resulting in the highest, maize stover and maize grain yields as well as the largest cob sizes. The combination of Muccuna and TSP also had high yields though the value was slightly lower than that of NCPR and JPR.

Changes in crop and soil management practices alter the dynamics of organic matter turnover in soils thereby influencing the transformation and supply of plant available P from water insoluble sources (Roy and Singh, 1999). In an experiment done by Mitra, Misra, Das and Sanu (1993) where low grade Udaipur PR (6.4%P) was applied to Kharif rice and Rabi groundnuts at a dose equal to the P requirements of both crops, the residual effects of P were studied on the subsequent Rabi crop or Kharif crop. Phosphate application as per requirement of both crops to one of the crops and growing the subsequent crop on residual P was found to be better than individual application of P to each of the crops. Taking into account yield increase and P recovery of both crops, application of P to groundnuts followed by a rice crop was found to be more efficient than the other way round. Available P content was generally higher after the harvest of groundnut crop than after rice, probably due to higher P removed by the rice compared to groundnuts and also high Ca^{2+} requirement by the groundnuts thus using Ca^{2+} from the PR and increasing rate of dissolution.

Hong-Qing, Xue-Yuan, Jing-Fu, Feng-Lin, Jing and Fan (1996) carried out field experiments, to evaluate the effect of direct application of phosphate rock, on red upland soils (Ultisols) at three different places using rapeseed as the test crop. The results indicated that for the first year's crop, the rapeseed yields with phosphate rock treatment and triple superphosphate treatment were almost identical when their rate of phosphorus application was the same but when the same level of phosphorus fertilizer was applied, the residual effect of phosphate rock was better than that of triple superphosphate, and the residual effect of all phosphorus fertilizers on winter crop yields increased with the increase of the amount of phosphorus applied. Hong-Quing *et al.*, (1996) also reported that, with the application of phosphate rock, the pH value, the amount of available phosphorus and exchangeable Ca^{2+} and Mg^{2+} of soils went up, whereas the content of active Al^{3+} in soils decreased.

3.0 MATERIALS AND METHODS

An experiment was conducted in the field and in the greenhouse to evaluate the effect of crop sequence on the availability of P for a maize crop when DPR was used as the P source for a previous crop. Two field sites were used; Farmers Development Trust farm (FDT) in Nyamajura and Africa University farm (AU). The soil at AU is a red sandy clay loam, Fersiallitic 5E soil under Zimbabwe soil classification system (Nyamapfene, 1991). Soils at FDT and AU are slightly acid sandy loam and strongly sandy clay loam loamy sand respectively. The FDT and the greenhouse soils are both Orthoferallitic 7G soils based on Zimbabwe's soil classification (Nyamapfene, 1991).

3.1 TREATMENT STRUCTURE

The treatments in the field and greenhouse comprised of five crops; groundnuts (*Apios americana*), cowpeas (*Vigna ecsulentus*), rapeseed (*Brassica napus*), pigeon peas (*Cajanus Cajun*) and sugar beans (*Phaseolus valguris*) combined factorially with five P levels (four DPR and one DSP). Both in the greenhouse and in the field, the experiments were laid out in a randomized complete block design with 25 treatments and three replicates (Table 3.1). The crops were harvested, their stover was turned into the soil (with the exception of rapeseed whose residues were not turned in) and maize (*Zea mays*) was grown using the residual P.

Table 3.1 The treatment combination adopted for the field and greenhouse experiments

DPR	INITIAL CROPS				
RATES	RS	GN	PP	SB	CP
P0	RSP0	GNP0	PPP0	SBP0	CPP0
P1	RSP1	GNP1	PPP1	SBP1	CPP1
P2	RSP2	GNP2	PPP2	SBP2	CPP2
P3	RSP3	GNP3	PPP3	SBP3	CPP3
P4	RSP4	GNP4	PPP4	SBP4	CPP4

Key

Previous crop	**Phosphate level**
CP-Cowpeas	P0- No P
PP- Pigeon pea	P1- 40 kgP_2O_5/ha
SB- Sugar bean	P2- 80 kgP_2O_5/ha
RS- Rape seed	P3- 120 kgP_2O_5/ha
GN- Groundnuts	P4-80kgP_2O_5/ha DSP

3.2 PROCEDURE

3.2.1 Greenhouse experiment

In the greenhouse, sugar beans, groundnuts, rapeseed, cow peas and pigeon peas were grown in black polythene bags containing 10kg soil each. The crops were harvested, and their stover turned in (except for rapeseed whose stover was removed, to comply with normal farmer

3.2.2 Field experiments

The field experiment was carried out at Africa University (AU) and Farmers Development Trust farm in Nyamajura (FDT). Sugar beans, cow peas, pigeon peas, groundnuts and rapeseed were grown for six weeks, harvested and their stover turned in as green manure (with the exception of rapeseed). A maize crop was grown after them in the same soil on the residual P. The experiments were laid out in a randomized complete block design with 25 treatments and three replicates to make 75 plots. The plot size adopted was 5m by 4m and the distance between the blocks being 1m. The distance from the edges of the research block was 1.5m on each side giving a gross plot of $1925m^2$.

Treatments

The treatments in the field comprised five crop species; groundnuts, cowpeas, rapeseed, pigeon peas and sugar beans combined factorially with five P levels ; 0, 40, 80 and 120 kg/ha P_2O_5 (0kgDPR, 444.4gDPR, 888.9gDPR, and 1333.3gDPR respectively per plot) and 80 kg/ha P_2O_5 as DSP (432.4g DPR per plot). To these five initial crops, potassium was added at the rate of 60kg/ha of K_2O (200g MOP/plot). To the legume crops, starter nitrogen at a rate of 50 kgN per hectare (289.9g AN/ plot) was applied in the form of AN. The initial crops were harvested after 6 weeks and their stover was turned in (except for rapeseed whose stover was not turned in to comply with normal farmer practices).

A maize crop was grown in the same soils using the residual P. Potassium was added to maize at planting at a rate of 60 kg /ha of K_2O (200g MOP per plot). To the maize crop, nitrogen in practice). A subsequent maize crop was grown in the same soil after 120 days. A sandy soil from Marange, 5G according to Zimbabwe soil classification system) was used for the greenhouse experiment. This is characteristic of the soil on most smallholder farms in Zimbabwe.

Treatments

Five initial crops; sugar beans, groundnuts, rapeseed, cow peas and pigeon peas combined factorially with five P rates 0, 40 (1.01g/pot), 80(2.02 g/pot) and 120 kg/ha P_2O_5 (3.03 g/pot) as DPR and 80 kg/ha P_2O_5 (0.728 g/pot) as DSP to give 75 treatments. The experiment was laid out as a randomized complete block design with three replicates. The plants were grown in black polythene bags containing 10kg of soil placed on greenhouse raised benches and the plants were watered using distilled water.

To the legume crops, starter nitrogen at a rate of 50 kg N/ha (0.659 g/pot) was applied in the form of ammonium nitrate (AN). Potassium was added at the rate of 60 kg/ha of K_2O (0.455 g/pot). To the groundnuts, gypsum was added as a calcium source at a rate of 200 kg/ha (0.909 g/pot) as is standard practice in Zimbabwe. After growing for 6 weeks the initial crops were harvested and the residues were incorporated into the soil as a green manure except for rapeseed. The residues were left to decompose for a period of 120 days after which maize was planted to all the pots with no further addition of P fertilizers. Nitrogen was however added to the maize crop in the form of AN at a rate of 200 kg N/ha (2.635 g/pot) and K_2O at 60 kg K_2O/ha (0.455 g/pot) was also added to all the pots. The maize was grown for 6 weeks then its above ground biomass was harvested. The greenhouse layout was as shown in Table 3.2.

the form of AN was applied at a rate of 200 kgN/ha (1.159 kg AN/plot). The AN application was split into 2 for the Africa University site where the soil is heavy (36 kgN/ha applied as 0.209 kg AN/plot at planting and 164 kgN/ha applied as 0.950 kg AN/plot at 6 weeks after emergence). For FDT where the soil is sandy, application of nitrogen was split into three (36 kgN/ha applied as 0.209kg AN/plot at planting and 82 kg N/ha as 0.475 kg AN/plot at six weeks and another 82 kg N/ha as 0.475 kg AN/plot at tussling.

3.2.3 Records

Maize agronomic records: germination percentage, plant stand, disease incidence, rainfall, yield, above ground biomass, 100 seed weight.

Groundnuts, sugar beans, cow peas and pigeon pea agronomic records: germination percentage, plant stand, disease incidence, rainfall and biomass.

Rapeseed agronomic records: germination percentage, plant stand, disease incidence, rainfall and above ground biomass.

Relative Agronomic Efficiency (RAE):

Relative agronomic efficiency of DPR with respect to DSP was determined for some of the measured parameters using the following formula:

$$RAE\% = \frac{\text{Yield at 80kg/ha P applied as DPR}}{\text{Yield at 80kg/ha P applied as DSP}} * 100$$

3.2.4 Soil and Dorowa phosphate rock characterization

Both the soils and the DPR were characterized before the experiment was carried out. The soil pH was determined before planting in both the field and the greenhouse soils and liming was done to bring the pH from pH from 4.8 and 5.01 ($CaCl_2$ scale) at AU and in the greenhouse respectively, to a pH of 5.1 which is recommended for most of the initial crops. Liming was done using agricultural lime at 1500 and 800 kg/ha in at AU and in the greenhouse respectively.

Soil samples were taken before planting and at harvest of the initial crops. Before any planting was done, the soils were characterized and the following determined; texture using the hydrometer method, organic carbon using the Walkely Black wet method, pH was determined in 0.01M $CaCl_2$, exchange acidity using the titration method, CEC by the ammonium saturation method, Ca and Mg using the ammonium acetate method and soil nitrogen using the colorimetric method. The soil was analyzed for P using the Melich-3 method to determine the available P and for N using the calorimetric method before planting the first crop, and after its harvest. All the soil analysis was done using the above mentioned methods following procedures as reported by Tagwira, (1992).

4.0 RESULTS and DISCUSSION

4.1 SOIL CHARACTERIZATION

Table 4.1 shows the initial chemical and physical characteristics of soil samples taken from AU, FDT and the soil from Marange Communal areas which was used in the greenhouse (GH) experiment.

Table 4.1 Some chemical and physical characteristics of soil samples from experimental sites

Analysis Description	AU	FDT	GH
Soil Texture	Sandy clay loam	Sandy loam	Loamy sand
Soil pH before liming	5.01	5.85	4.80
Available phosphorus (ppm)	17.8	37.4	8.90
Exchangeable potassium (me%)	0.63	0.18	0.12
Exchangeable calcium (me%)	8.58	1.19	0.14
Exchangeable magnesium (me%)	5.20	0.82	0.11
Available copper	1.42	1.19	0.27
Available zinc	T	T	T

All the three soils were acidic. The AU and greenhouse soils had low available P_2O_5. According to Zimbabwean fertilizer recommendations such soils require phosphate fertilizer to be applied to improve yields. The FDT soil had the highest soil available P_2O_5 of the three soils. This amount was above the critical level of 30ppm P_2O_5 (mehlich 3 extractable) sited by Jones and Piha (1989) in their research on Zimbabwean soils. However, even when available P_2O_5 is at or above the critical level, there is still need for maintenance phosphatic fertilizer dressings (Tagwira, 1992). Soil available P_2O_5 of the AU and Marange greenhouse soils would be classified as P deficient (Tagwira 1992). The AU soil had high exchangeable potassium levels while FDT and greenhouse soils had marginal quantities. All the three soils were deficient in zinc (Tagwira, Piha and Mugwira, 1993).

4.2 GREENHOUSE EXPERIMENT

4.2.1 Soil available P_2O_5 after growth of initial crops

Table 4.2 shows the significance of F values for soil available P_2O_5 determined in the greenhouse soil after growth of the initial crop. There was significant interaction ($P<0.001$) between applied P and initial crop on the amount of soil available P_2O_5. There were also significant differences amongst the initial crops ($P<0.001$) and the applied P rates ($P<0.001$) on the amount of soil available P_2O_5 after growth of the initial crops.

Table 4.2 Significance of F values from analysis of variance for soil available P_2O_5 in Marange soil after growth of initial crops, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value
Interaction of initial crop and DPR level on soil available P_2O_5	48	***
Differences amongst initial crops on soil available P_2O_5	4	***
Differences amongst DPR levels on soil available P_2O_5	4	***

*** denotes significance at P=0.001.

4.2.1.1 Effect of applied P level and initial crop on soil available P_2O_5

The significant interaction (P<0.001) between the initial crop and the applied DPR shows that different crops have different abilities to solubilize phosphate from DPR. With all the five initial crops, an increase in the DPR applied resulted in increased soil available P_2O_5 (Figure 1). With the exception of pigeon peas, the combination of DPR rate of 120 kg/ha P_2O_5 with each of the initial crops resulted in soil available P_2O_5 above the critical level of 30ppm (Mehlich 3 extractable) P_2O_5 sited by Jones and Piha, (1989). The highest soil available P_2O_5 was observed after groundnuts fertilized with 120 kg/ha P_2O_5 DPR. The order of performance of the initial crops in terms of soil available P_2O_5 after their growth at 120 kg/ha P_2O_5 DPR was as follows pigeon peas< cow peas< sugar beans< rapeseed< groundnuts. At all the DPR rates above zero, soil in which pigeon peas had been grown had the least available P_2O_5 (Figure 1) compared with the other initial crops.

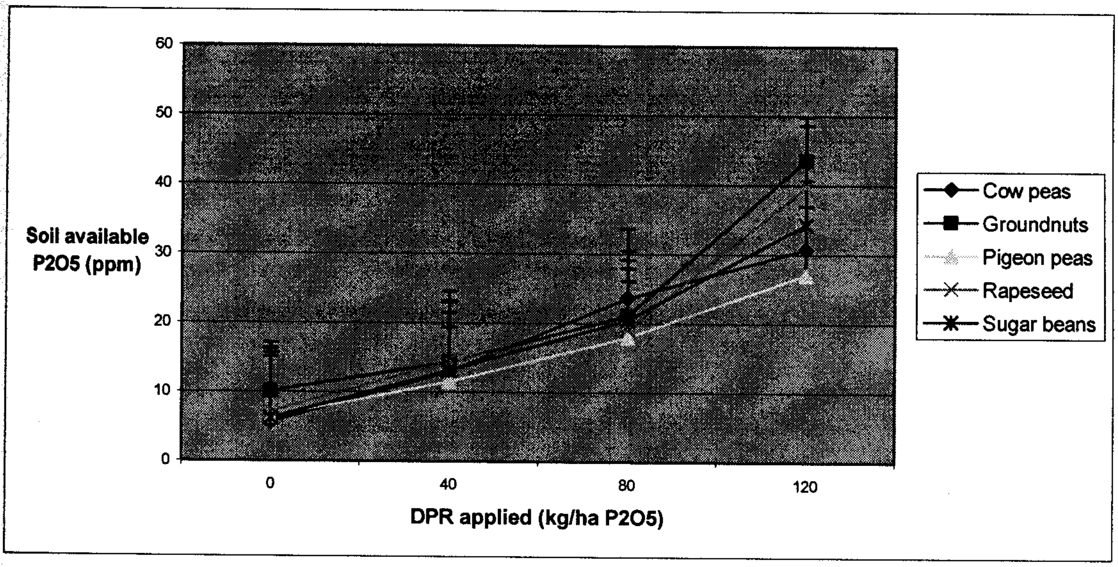

Figure 1 Soil available P_2O_5 (ppm) found after growth of initial crops fertilized at different DPR rates in the Greenhouse, 2006/2007 season.

At a DPR rate of 80 kg/ha P_2O_5, soil where cow peas had been grown had the most soil available P_2O_5. The applied DPR levels of 40 and 80 kg/ha P_2O_5 in combination with the different initial crops resulted in an increase in available P_2O_5. However, the soil available P_2O_5 observed at these applied DPR levels was below the critical level cited for Zimbabwean soils.

Figure 2 shows the change in available P_2O_5 with increase in DPR applied for all the crops combined. There were significant differences in the amount of available P_2O_5 among the DPR rates applied. As the applied P rates increased from 0 to 40, 80 and 120 kg/ha P_2O_5, amount of available P_2O_5 in the soil increased by 88 %, 189 % and 396 % respectively. Only at DPR rate of 120 kg/ha P_2O_5 was the residual P above the critical level of 30ppm P_2O_5 (Jones and Piha, 1989) (Figure 2). At an application rate of 80 kg P_2O_5/ha DPR and DSP, mean soil available P_2O_5 was 20.44 and 85.6ppm respectively. This gives a relative agronomic effectiveness (RAE) 23.9%.

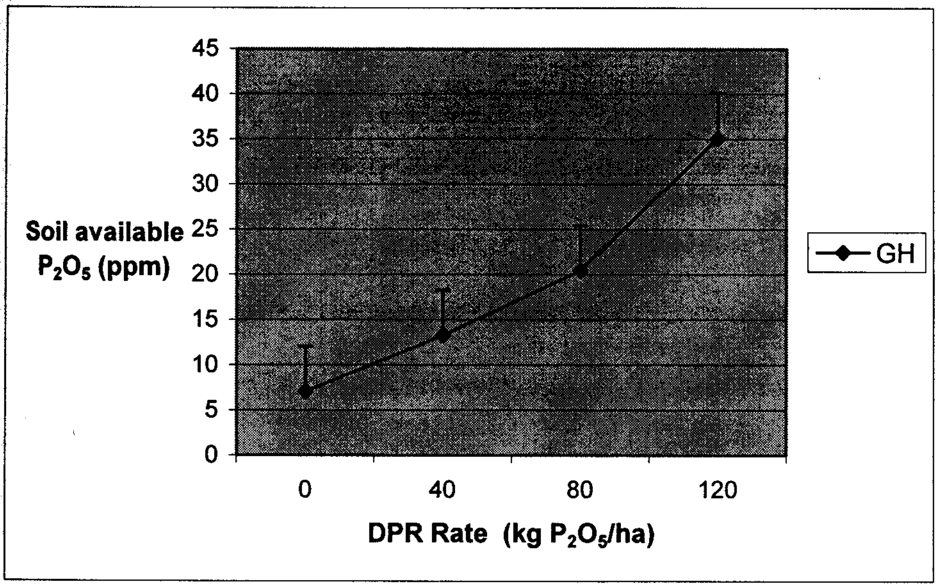

Figure 2 Effect of different levels of DPR on available P_2O_5 after growth of initial crops in the Greenhouse, 2006/2007 season.

At available P_2O_5 of 10ppm, the Marange soil used in the greenhouse is considered to be acutely deficient in P according to Tagwira (1992). This means, given that all other plant nutrients were available, phosphorus would limit yield of a crop grown in such a soil. Soil available P_2O_5 above 30ppm is sufficient for crop growth (Jones and Piha 1989). Based on this, at DPR rate of 120 kg/ha P_2O_5, all initial crops with the exception of pigeon peas, would provide enough available P for the subsequent maize crop. However, in a soil with available P_2O_5 above the critical level there would still be need for maintenance phosphate fertilizer dressing (Tagwira, 1992) to ensure that the soil is not mined of nutrients through crop harvests. At the lower DPR rates (0- 80 kg/ha P_2O_5), the residual soil available P_2O_5 was below the critical level (30ppm) thus inadequate for growth of maize or other cereal crops in the same soil without supplementary phosphate fertilizer dressing. Yield increase of one to two thirds can be expected if adequate P is applied, assuming that all other nutrients are in sufficient amounts (Tagwira, 1992).

Results show that at the initial three DPR rates (0, 40 and 80 kg/ha P_2O_5) there is still need for additional phosphate fertilizer dressing on the following crop. However, the amount of this supplementary dressing decreases with increase in the DPR rate used.

The RAE of DPR with reference to DSP in this experiment was low (23.8 %). This RAE is lower than what has been reported by Singh et al. (2001) for more reactive PRs such as the Tanzanian Minjingu PR (68-110 %) and the Kenyan Gituamba PR (120 %) in direct application. Chien (2001) indicated that the performance of finely ground PR's in comparison to soluble fertilizers depends on the P Source. The low agronomic efficiency of DPR observed in this experiment could be attributed its low neutral ammonium soluble P_2O_5 (0.8 % P_2O_5) (Fernandes, 1978). Govere, Chien and Fox (2003) and Dhliwayo (1999) also reported low agronomic efficiency when using DPR in direct application. The low RAE of DPR with respect to DSP after the first crop could be due to the limited time that DPR was in contact with the soil (6 weeks). Chien (2001) reports that RAE of PRs increases with increase in length of growing season.

Results from this experiment suggest that to get high residual P from DPR, higher application rates should be applied. Fardeau (1997) cautions that a policy of replenishment using high rates of PR applications must be carefully examined before its implementation to predict the soils where such recommendations can be efficient. However, given the low neutral ammonium solubility (0.8 % P_2O_5) of DPR, larger quantities applied may have potential to release more soil available P_2O_5.

Contrary to results in this experiment, pigeon peas have been observed to better solubilize PRs when compared to other crops due to its release of piscidic acid into the rhizosphere (van Straaten, 2002). The inferior performance of pigeon peas in this experiment could have been due to the soil used and length of growing period. While pigeon peas can be grown in a wide range of soils, it grows best in well-drained medium heavy loams (New Forest Projects, 2007). Also in this experiment, pigeon peas were only grown for 49 days. Pigeon peas are a woody perennial which can take up to 260 days to produce seed, (Giller and Wilson, 1991). The reduced growing period (49 days) could also account for its inferior performance. At the stage of harvest, the pigeon peas may not have grown long enough to exhibit the effects observed by Van Straaten (2002). In this experiment the rhizosphere processes were only allowed for a short period compared to the total effects when the full growing season is allowed.

The higher soil available P_2O_5 observed after groundnuts could be attributed to groundnut rhizosphere activity enhancing more DPR solubilization. A high population density of phosphobacteria in groundnuts has been reported by Ponmurugan and Gopi (2006). Of ten crops studied, GP02 strain of phosphatase enzyme isolated from groundnut rhizosphere was also reported to have the highest activity (Ponmurugan and Gopi, 2006).

Amount of soil available P_2O_5 found in rapeseed rhizosphere was relatively high in the greenhouse medium acid soil. This is in agreement with Hinsinger and Gikes (1997) who reported high release of PR by rapeseed planted in an acid mineral substrate.

Figure 3 shows the mean available P_2O_5 levels found in the greenhouse soils after each initial crop grown. There were significant differences ($P<0.001$) in amount of soil available P found amongst the different initial crops after their harvest in the greenhouse.

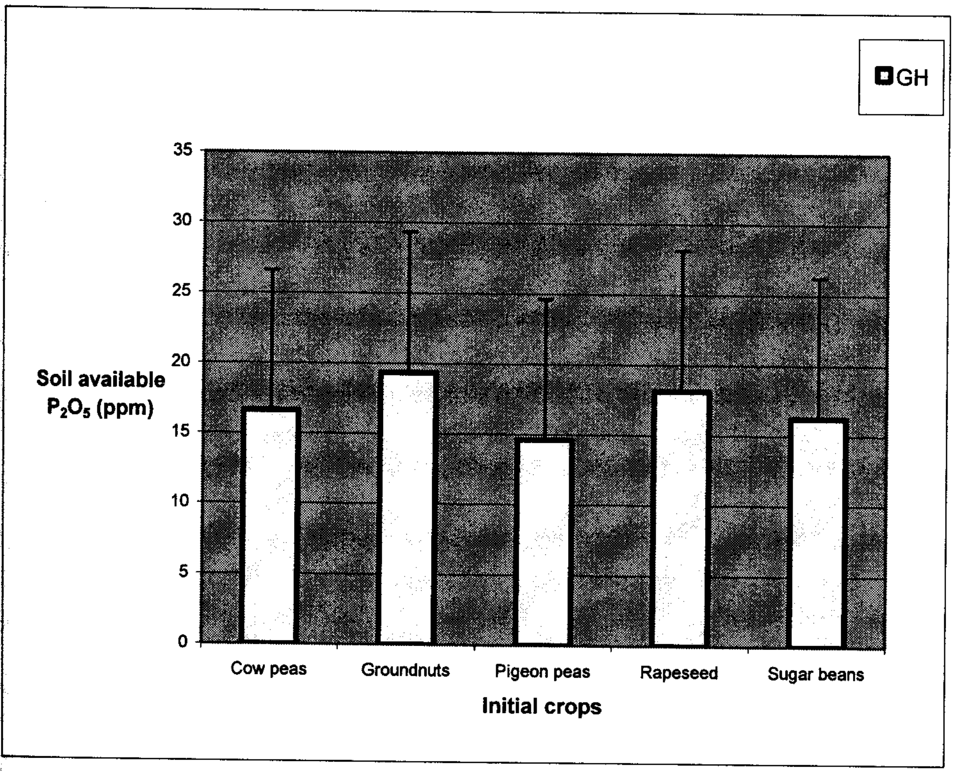

Figure 3 Mean soil available P_2O_5 after growth of different initial crops in the Greenhouse, 2006/2007 season.

The soil in which pigeon peas was grown had the least available P_2O_5. Soil in which groundnuts were grown had the highest soil available P_2O_5 (24, 4 % higher than pigeon peas). The order of performance of the initial crops with reference to soil available P_2O_5 after their growth was as follows: pigeon peas< sugar beans and cow peas< rapeseed < groundnuts.

All the five crops contributed to an increase in soil available P_2O_5 since amount found after them was higher than the initial P status of the soil. The extent to which each crop increased the soil available P_2O_5 varied. The mean soil available P_2O_5 after growth of all five initial crops is below the critical point (30ppm) for available soil P_2O_5 for crop growth. Increases in yield maybe experienced with adequate dressing of phosphatic fertilizer in a soil with such P_2O_5 levels (Tagwira, 1992). Results show that depending on the initial crop used, the supplementary amount of P_2O_5 needed as phosphate fertilizer dressing would vary. Growing of groundnuts with application of DPR would result in the least amount of the supplementary phosphate fertilizer needed to be applied while pigeon peas would need the most. The superior performance of groundnuts may be attributed to its rhizosphere activity as already mentioned in section 4.2.1.1.

4.2.2 Soil mineral Nitrogen after growth of initial crops

Table 4.3 shows the significance of F values for soil mineral nitrogen determined in the greenhouse soil after growth of the initial crop. There was no significant interaction ($P<0.05$) between applied P_2O_5 and initial crop on the soil mineral nitrogen. There were however significant differences amongst the initial crops ($P<0.05$). There were no significant differences ($P=0.05$) amongst the applied P rates on the amount of soil mineral nitrogen after growth of the initial crops.

Table 4.3 Significance of F values from analysis of variance for soil mineral N determined for Marange soil after growth of initial crops, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value
Interaction of initial crop and DPR level on soil mineral nitrogen	48	NS
Differences amongst initial crops on soil mineral nitrogen	4	*
Differences amongst DPR levels on soil mineral nitrogen	4	NS

* denotes significance at P=0.05. NS = not significant at P=0.05.

There were significant differences ($P<0.05$) in soil available nitrogen after growth of the different initial crops (Table 4.4). Soil mineral nitrogen found after growth of all five initial crops was lower than the original amount before planting. This means that there was a net decline in mineral nitrogen even where the legumes (cow peas, sugar beans, groundnuts and pigeon peas) had been grown. Of the four legumes, nitrogen in the soil where groundnuts had been grown was the least while cow peas, pigeon peas and sugar beans had the highest mineral nitrogen (Table 4.4). Amount of mineral nitrogen after growth of groundnuts was not significantly different from that found after rapeseed.

Table 4.4 Effect of initial crop and applied P fertilizer on amount of soil mineral nitrogen (ppm) after growth of initial crops in the greenhouse, 2006/2007 season.

Initial Crop	P_2O_5 level (ppm)						
	0	40 kg/ha (DPR)	80 kg/ha (DPR)	120 kg/ha (DPR)	80 kg/ha (DSP)	Mean	P value
Cow peas	46.8	44.6	39.4	49.7	39.2	43.9	*
Groundnuts	38.0	40.7	39.7	33.9	38.3	38.1	*
Pigeon peas	60.3	38.9	47.2	41.1	42.3	46.0	*
Rapeseed	29.4	34.3	38.5	40.8	34.5	35.5	*
Sugar beans	38.6	31.2	40.3	52.0	38.8	40.2	*
Mean	42.6	37.9	41.0	43.5	38.6	40.7	
$P_{(0.05)}$	NS	NS	NS	NS	NS		

* denotes significance at $P<0.05$ and NS= not significant at $P=0.05$.
CV 21.7%
$LSD_{(0.05)}$ 14.53

Contrary to results from this experiment, Giller and Wilson (1991) reported that in the tropics groundnuts usually fix more nitrogen when compared to pigeon peas, sugar beans and cow peas. Giller and Wilson (1991) also noted that the ability of legumes to fix nitrogen varied enormously between grain legumes, between different genotypes of the same crop and between different environments in which the crops are grown.

The net decline in N observed after growth of the legumes could be attributed to the fact that N analysis was done before the incorporation of the initial crops into the soil. Had the analysis been done after incorporation and decomposition, soil available N may have been higher.
Soil nitrogen Analysis in this experiment only measured soil mineral nitrogen. It is possible that total nitrogen in the soil would have been higher and would show an indication of N release over time.

The soil available P_2O_5 before fertilizer addition was very low (8.9ppm) and at harvest, average available P_2O_5 after each of the crops was still below the critical level of 30ppm (section 4.2.1.2). Graham and Vance (2003) report that nodulation, N fixation and survival of rhizobia in soil are particularly affected under low soil P. Results from work done in Tanzania by Giller, Amijee, Brodrick and Edje (1998) also showed that in low P soils legumes can fix very little nitrogen.

The low mineral nitrogen observed after growth of rapeseed can be attributed to the fact that rapeseed does not fix nitrogen.

4.2.3 Soil pH after growth of initial crops

Table 4.5 shows the significance of F values for pH of Marange greenhouse soil after harvest of the initial crops. There was no significant interaction on initial crop and applied DPR rate on soil pH. However, there were significant differences amongst the initial crops (P<0.001) and DPR levels (P<0.001) in the soil pH.

Table 4.5 Significance of F values from analysis of variance for soil pH determined for greenhouse Marange soil after growth of initial crops, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value
Interaction of initial crop and DPR level on soil pH	48	NS
Differences amongst initial crops on soil pH	4	***
Differences amongst DPR levels on soil pH	4	***

*** denote significance at P=0.001 and NS = not significant at P= 0.05.

4.2.3.1 Effect of different initial crops fertilized at different P_2O_5 levels on soil pH

Figure 5 shows the differences in pH observed after growth of the different initial crops. Results show significant differences (P<0.001) in pH amongst the different initial crops grown in the greenhouse. The soil pH observed in the greenhouse after growth of all the initial crops ranged from 5.731-6.105. This means there was a rise in soil pH of about (0.021-0.395) from the initial soil pH of 5.71. The lowest pH change of 0.2 was observed in groundnuts and the highest (0.40) in rapeseed (Fig 4).

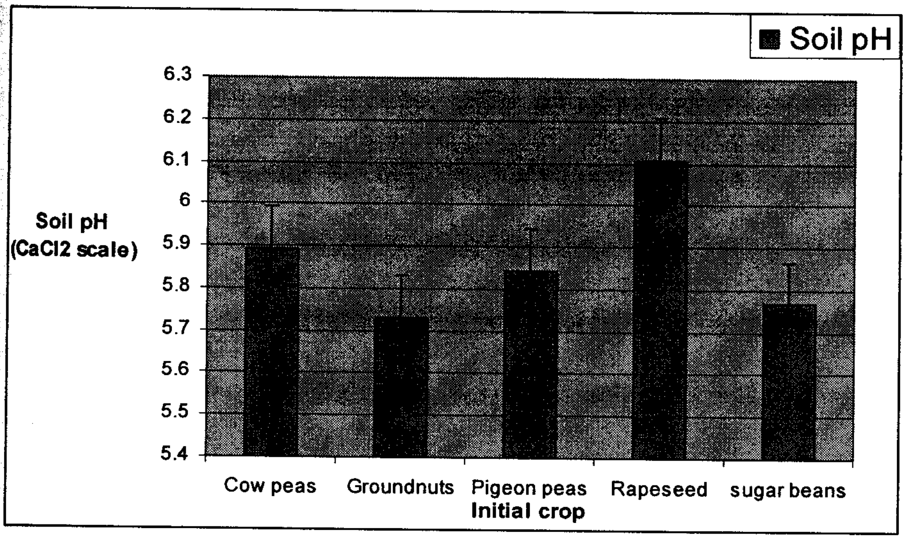

Figure 4 Soil pH after growth of initial crops in the greenhouse, 2006/2007 season

In the dissolution of PRs there is release of calcium (Fagiya and Ma, 2006) and this could account for the overall increase of pH observed after growth of all the initial crops. The difference in the extent of pH increase could be partly due to the difference in extent of dissolution occurring per crop. The more the dissolution, the more the Ca released and thus the higher the rise of pH. However, the Ca uptake of each crop also affects the amount remaining in the soil of that released from DPR solubilization. For example, pH rise in groundnut rhizosphere was very little. This could be because of the high Ca demand of groundnuts.

Legumes have been known to release acidic protons into their rhizosphere as they grow (McLenaghen *et al.*, 2004). This could account for the lower pH in the legume rhizosphere observed in this experiment when compared with that of rapeseed. The RAE of PRs has been shown to be enhanced by low pH (Harris, 1985; Chien 2001). Crops that acidify the rhizosphere would therefore enhance the dissolution of P from DPR. Applying DPR to such crops could benefit a following crop grown in the same soil in a crop sequence. While legumes may have the ability to acidify the soil and make P from less soluble sources such as PRs more available, they could also increase soil N. Thus, inclusion of legumes such as the groundnuts and pigeon peas in a crop sequence in the direct application of DPR may have the dual effect of improving soil N and P.

The highest pH rise (0.395) was observed after growth of rapeseed. On the contrary, rapeseed has been reported to release citric and malic acid into its rhizosphere (Chien, 2001) thus it would be expected to have lower rhizosphere pH.

4.2.3.2 Soil pH observed at the different applied P_2O_5 levels

Figure 5 shows the change in pH after growth of initial crops at the different P levels. Results show significant differences ($P<0.001$) in pH amongst the different P levels in the greenhouse. There was a significant increase in pH where P was applied as DPR and as DSP in comparison to the control. Soil pH where P was applied at the various DPR levels was not significantly different from where P was applied as DSP. With DPR application of 80 kg P_2O_5/ha, soil pH rose by 0.19 units. With DSP application at the same level, soil pH rose by 0.2 units.

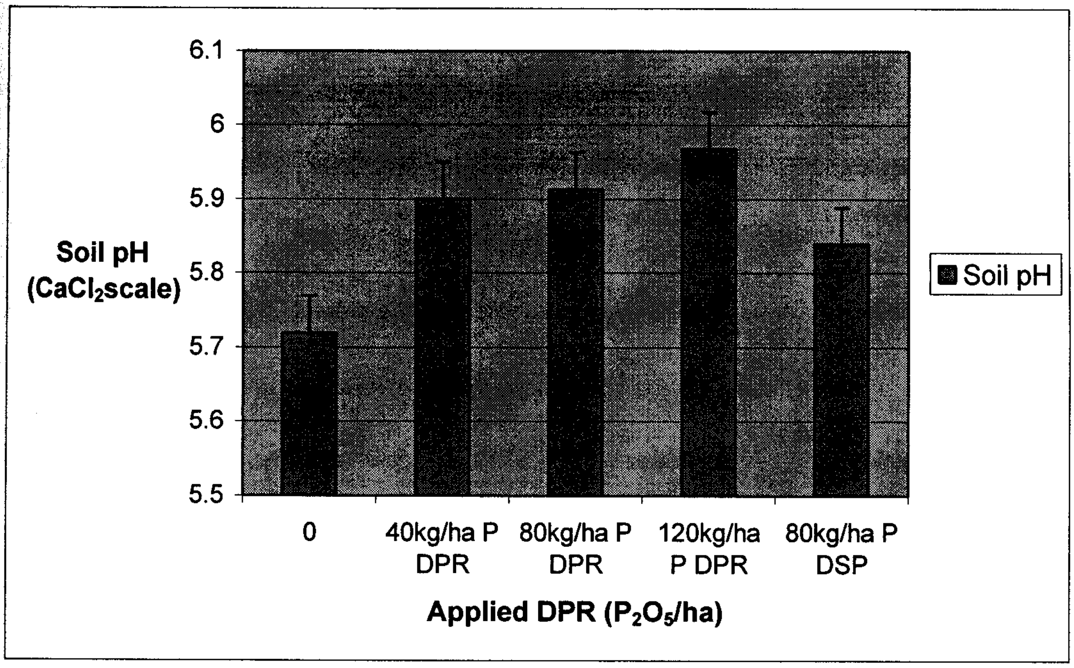

Figure 5 Soil pH after growth of different initial crops fertilized at different P levels in the Greenhouse, 2006/2007 season.

The rise in pH where P_2O_5 had been applied as DSP could be attributed to the high Ca content in Zimbabwean manufactured phosphate fertilizers such as the one used in this experiment. Tagwira, Piha and Mugwira (1993) also observed a rise in soil pH where P had been added as the Zimbabwean manufactured superphosphates which was attributed to the high Ca content of the fertilizer. Contrary to results from this experiment Bolan *et al.* (2003) observed a drop in pH in soil where super phosphates had been applied. This was attributed to the dissolution of monocalcium phosphate to form dicalcium phosphate (DCP) with a release of phosphoric acid close to the fertilizer granules (Bolan *et al.* 2003).

4.2.3.3 Correlation of applied DPR rate and soil pH

A strong correlation between soil applied DPR and soil pH was observed (Figure 6).

$Y= 0.0019X +5.761$

$R^2= 0.82$

$r= 0.91$

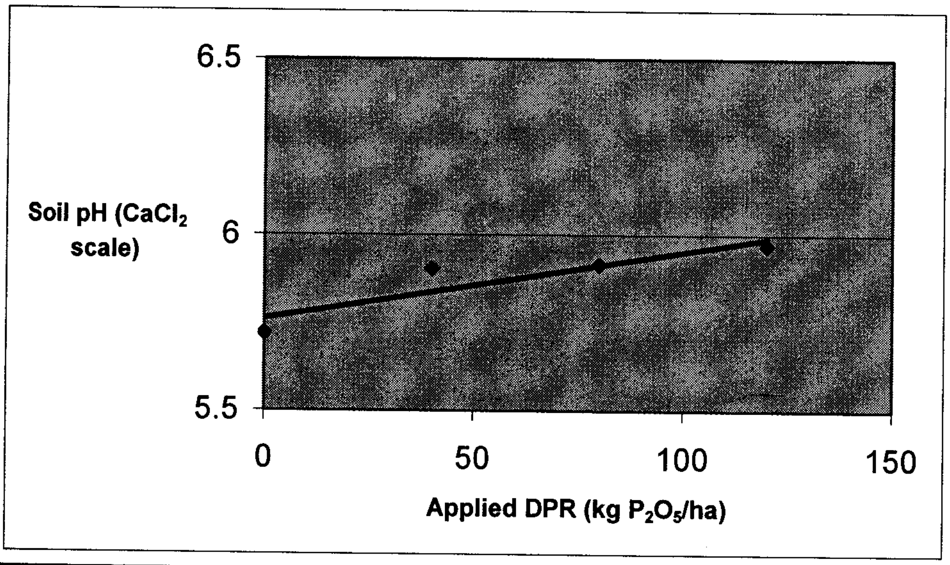

Figure 6. Correlation of applied DPR rate and pH after growth of initial crops in the greenhouse, 2006/2007 season.

As applied DPR rate increased, so did the soil pH (Figure 6). The more the DPR dissolution, the more the Ca released, thus the higher the pH observed. This is in agreement with observations by Fagiya and Ma (2006) who reported of pH increase where P had been applied as PR. Nekesa, Okalebo, Othieno, Thuita, Kipsat, Bationo, Sangina, Kimettu and Vanlauwe, (2005) also reported that Minjingu PR effectively increased soil pH in an acid Kenyan soil (pH 5.01) and thus recommend that it be used as a liming material. However, Fardeau (1997), based on findings in a study done to investigate fertility replenishment and liming using phosphate rocks, recommended that the liming effect of PR must be considered as limited or near zero, although PR can provide calcium ions to soils and/or crops.

4.2.4 Maize above ground biomass yield

As indicated in Table 4.6, there was a significant interaction ($P<0.05$) between initial crop and DPR level on maize biomass yield. However there were no significant differences ($P=0.05$) amongst the initial crops and the applied P fertilizer rates.

Table 4.6 Significance of F values from analysis of variance for maize above ground biomass yield at 6 weeks determined in the greenhouse experiment, 2006/2007 season.

Variate	Significance of F value
Interaction of initial crop and DPR level on maize biomass	**
Differences amongst initial crops on maize biomass	NS
Differences amongst DPR levels on maize biomass	NS

** denotes significance at P= 0.01, and NS = not significant at P= 0.05

4.2.4.1 Effect of applied P_2O_5 and initial crops on maize above ground biomass yield

There was significant interaction ($P<0.05$) between initial crop and applied P_2O_5 level in the above ground biomass of maize at 6 weeks after emergence. The RAE of DPR with respect to DSP at 80 kg/ha P_2O_5 was 107, 91, 59, 69 and 59 % for soils to which cow peas, groundnuts, pigeon peas, rapeseed and sugar beans had been grown respectively. The highest maize biomass was achieved with a combination of DPR rate of 40 kg/ha P_2O_5 and initial crop of groundnuts. There were however, no significant differences ($P < 0.05$) amongst the different P levels and initial crops in the maize biomass at 6 weeks after emergence (Table 4.7). The differences in soil available P_2O_5 observed (section 4.2.1.3) after growth of initial crops did not result in significant differences in biomass yield in the greenhouse.

Table 4.7 Effect of initial crop and P_2O_5 level on above ground biomass yield of maize observed in the greenhouse, 2006/2007 season.

Crop	P level (P_2O_5)						
	0	40 kg/ha (DPR)	80 kg/ha (DPR)	120 kg/ha (DPR)	80 kg/ha (DSP)	Mean	P value
Cow peas	3.22	3.82	3.39	2.35	3.16	3.19	NS
Groundnuts	1.70	5.20	2.47	3.65	2.71	3.14	NS
Pigeon peas	2.11	2.79	2.83	3.28	4.77	3.16	NS
Rapeseed	4.43	2.16	3.04	3.20	4.38	3.44	NS
Sugar beans	4.31	2.65	2.07	3.85	3.49	3.28	NS
Mean	3.15	3.32	2.76	3.27	3.70	3.28	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

NS means not significance at ($P = 0.05$).
CV% 16.2
$LSD_{(0.05)}$ 2.018

The agronomic effectiveness of DPR with respect to DSP was higher for maize above ground biomass yield than it was for the observed soil available P_2O_5. This may be attributed to the continual release of P from DPR from the time of the initial crops to the maize growing period. More P may have been available to the maize than what had been determined before maize planting. Other factors can also affect agronomic effectiveness.

The differences in soil available P_2O_5 observed in section 4.2.1 did not translate to differences in biomass yield. It would have been expected that biomass yield be higher where DPR had been applied due to the expected higher residual effect of PRs with respect to soluble fertilizers such as DSP. Even the DSP treatment did not produce higher yields. Nekesa *et al.* (2005) while evaluating the residual effect of Minjungu PR on maize in the second growing season observed higher residual P with Minjingu and subsequently higher maize yield when compared to DAP. Since no response was obtained even where DSP had been applied, it would seem that other limiting factors may have hindered response to applied P. Mowo (2000) while evaluating the residual effect of P from Minjingu PR also observed no significant differences in the performance of maize between the PR and TSP and these results were attributed to other limiting factors such as N and rainfall hindering maize response to P.

4.3 FIELD EXPERIMENT

4.3.1 Soil available P_2O_5 after growth of initial crops

There was no significant interaction of initial crop and applied P_2O_5 on soil available P_2O_5 both at AU and FDT (Table 4.8). There were however significant differences ($P<0.001$) in available P_2O_5 at different rates of applied P_2O_5 at AU and FDT. There were also significant difference in available P_2O_5 for the soils from different initial crops at FDT ($P<0.05$) and AU ($P<0.001$).

Table 4.8 Significance of F values from analysis of variance for soil available P_2O_5 after growth of initial crops at FDT and AU field site during the 2006/2007 season.

Variate	Degrees of freedom	Significance of F value AU	Significance of F value FDT
Interaction of initial crop and DPR level on soil available P_2O_5	48	NS	NS
Differences amongst initial crops on soil available P_2O_5	4	*	***
Differences amongst DPR levels on soil available P_2O_5	4	***	***

*** and* denotes significance at P= 0.001 and P=0.05. NS= not significant at P= 0.05

4.3.1.1 Mean available P_2O_5 after initial crops

Tables 4.9 and 4.10 show the effect of different rates of DPR and each initial crop on soil available P_2O_5 after harvest of the initial crop at FDT and AU respectively. There was no significant interaction observed between initial crop and P_2O_5 applied on the amount of soil available P_2O_5 at AU and FDT. There were significant differences in available P_2O_5 from the different rates of P applied at FDT (P<0.001) and at AU (P<0.001) as indicated in Tables 4.9 and 4.10 respectively. In the field experiments at AU and FDT, soil to which P had been applied as DSP at 80kg P_2O_5 /ha had higher available P_2O_5 compared to the same rate of DPR.

Table 4.9 Effect of initial crop and applied P_2O_5 (ppm) in soil available P_2O_5 at FDT, 2006/2007 season

	Cow peas peas	Ground nuts	Pigeon peas	Rapeseed	Sugar beans	Mean	P
0	39.5	20.7	29.8	42.5	36.6	33.8	***
40 kg/ha DPR	28.1	47.7	31.8	74.0	23.1	41.0	***
80 kg/ha DPR	32.3	46.5	26.8	20.7	33.4	32.0	***
120 kg/ha DPR	52.9	32.9	29.3	36.9	36.2	37.6	***
80 kg/ha DSP	140.3	128.0	113.1	166.0	95.2	128.5	***
Mean	58.6	55.2	46.2	68.0	44.9	54.6	
$P_{(0.05)}$	*	*	*	*	*		

* and *** denote significance at P=0.05 and P= 0.001 respectively
CV% 19.31
LSD $_{(0.05)}$ 37.31

Table 4.10 Effect of initial crop and applied P_2O_5 (ppm) in soil available P_2O_5 at AU, 2006/2007 season

	Cow peas peas	Ground nuts	Pigeon peas	Rapeseed	Sugar beans	Mean	P
0	6.7	10.2	23.6	10.6	15.4	13.3	***
40 kg/ha DPR	8.3	18.0	33.2	15.6	17.9	18.6	***
80 kg/ha DPR	20.3	33.1	45.3	30.0	24.7	30.7	***
120 kg/ha DPR	24.7	63.8	62.9	50.6	56.1	51.6	***
80kg/ha DSP	90.5	119.2	113.1	88.8	117.2	105.7	***
Mean	30.1	48.9	55.6	39.1	46.3	44.0	
$P^{(0.05)}$	***	***	***	***	***		

*** denotes significance at P= 0.001
CV% 20.1
$LSD_{(0.05)}$ 17.42

At FDT, there were no significant differences (P<0.05) in soil available P_2O_5 amongst the three DPR rates. At FDT, the control performed as well as the three DPR rates in the amount of soil available P_2O_5 after growth of initial crops. At AU, the higher the DPR rate, the higher the soil available P_2O_5 observed after growth of the initial crops (Figure 7). The agronomic efficiency of DPR with respect to DSP at 80 kg/ha P_2O_5 was 29 and 24.9 % at AU and FDT respectively.

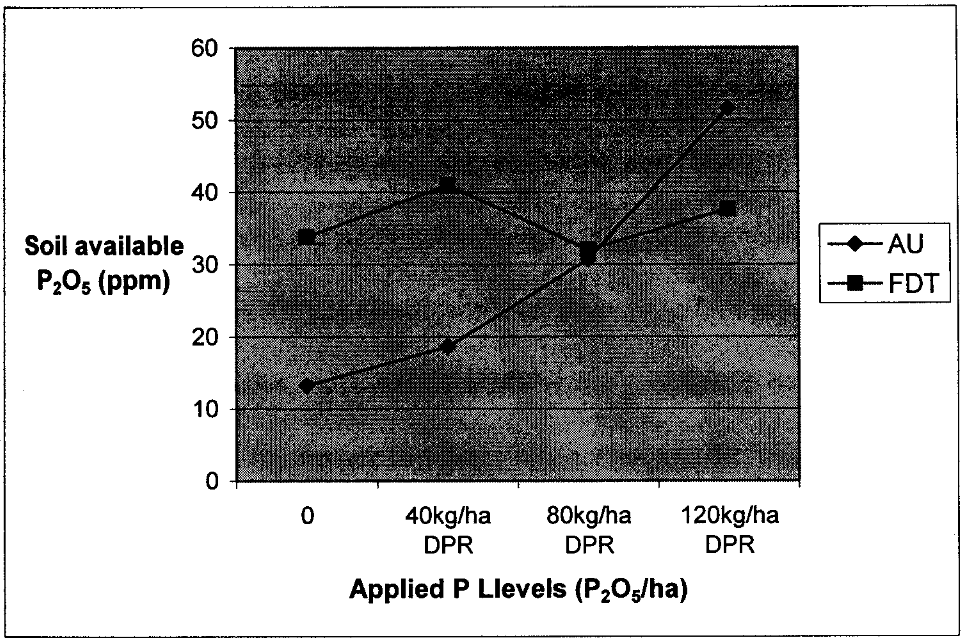

Figure 7 Soil available P_2O_5 at different applied DPR rates at AU and at FDT , 2006/2007 season.

There was no evidence of DPR dissolution at FDT since the amount of soil available P_2O_5 at the three DPR rates was not significantly different from the control. This could be a result of the high initial pH (5.85 $CaCl_2$) of the soil which could have negatively affected solubility of DPR applied at the different rates. These results are in agreement with White and Johnson, (1980) who reported that no PR source was effective on soils having pH levels above 5.5-6.0. Fardeau (1997) also reported that replenishment of soil P fertility using phosphate rocks can be partly obtained in soils whose pH is really lower than 5.8. At FDT, there was high initial P_2O_5 (37.4 ppm) which could have also affected DPR dissolution. Based on mass action law (Hammond, Chien and Mokwunye, 1986), an increase/ accumulation of the products, Ca^{2+} in this case, will slow down the rate of reaction.

The results from AU site suggest that higher DPR levels will provide higher soil available P_2O_5 which could sustain a good subsequent maize crop. Fardeau (1997) however cautions that a policy of replenishment using high rates of PR applications must be carefully examined before its implementation to predict the soils where such recommendations can be efficient. DPR applications of 80 and 120 kg/ha P_2O_5 resulted in available P_2O_5 levels above the critical point of 30 ppm P_2O_5.

In the field experiment the RAE of DPR was observed to be very low at both sites. Chien (2001) reported that the longer the growing season, the more the P released from PRs. In this experiment, the low agronomic efficiency of DPR could be attributed to the short duration (8 weeks) the initial crops were allowed to grow. Similarly, Nekesa *et al.* (2005) observed lower available P from Minjingu PR as compared to a more soluble fertilizer Diamonium phosphate (DAP) after the first planting season. However, after the second season, soil available P where Minjingu PR had been applied was found to be higher than that of DAP.

The low agronomic efficiency of DPR could also be attributed to its characteristics. According to Chien (2001), performance of finely ground PRs in comparison to soluble fertilizers depends, among other things on the PR source. Dorowa Phosphate Rock was classified as a hydroxy-fluor-apatite with low neutral ammonium citrate solubility (Fernandes, 1978). This could be the reason to its very low agronomic efficiency. This is also in agreement with conclusions made by Govere *et al.* (2003) that DPR is not as effective as soluble P fertilizers when applied directly. Performance of PRs applied directly also depend on the length of the growing season where more P is released with longer seasons as compared to shorter ones (Chien, 2001).

4.3.1.2 Mean available P_2O_5 after growth of each initial crop

Significant differences (P< 0.001) amongst crops in the amount of available soil P_2O_5 after growth of initial crops were noted at AU and at FDT (Table 4.2). At both sites, soil available P_2O_5 after all the initial crops was higher than 30 ppm. In the red sandy clay loam AU soils, cowpeas gave the least available P_2O_5 and pigeon peas performed as well as groundnuts (Table 4.12).

Table 4.11 Mean soil available P_2O_5 after growth of each initial crop fertilized with different levels of DPR and DSP at AU and FDT, 2006/2007 season.

Crops	Available soil P_2O_5 (ppm)	
	AU	FDT
Cow peas	30.1	58.6
Groundnuts	48.9	55.2
Pigeon peas	55.6	46.2
Rapeseed	39.1	68.0
Sugar beans	46.3	44.9
CV%	24.1%	21.5%
LSD $_{(0.05)}$	7.79	16.68
P $^{(0.05)}$	***	***

*** denotes significance at P= 0.001.

In the slightly acid sandy loam FDT soils (pH 5.85 $CaCl_2$ scale), highest available P_2O_5 was found after growth of rapeseed (Figure 8). The difference between the initial original soil available P_2O_5 and that after rapeseed and cow peas was greater at FDT (30.6 and 21.2 ppm respectively) than at AU (21.3 and 12.3 ppm). This means that more residual P_2O_5 was found at FDT than at AU after rapeseed and cow peas. For other legumes, more residual P_2O_5 was found at AU as compared to FDT. The difference between the original soil available P_2O_5 and that after groundnuts, pigeon peas and sugar beans at AU and at FDT was 31.1; 37.8; 28.5 and 17.8; 8.8; 7.5 ppm respectively, an indication that more residual P was found at AU when compared to FDT. Relatively high available soil P_2O_5 was found in the groundnut rhizosphere (Figure 8) at both sites.

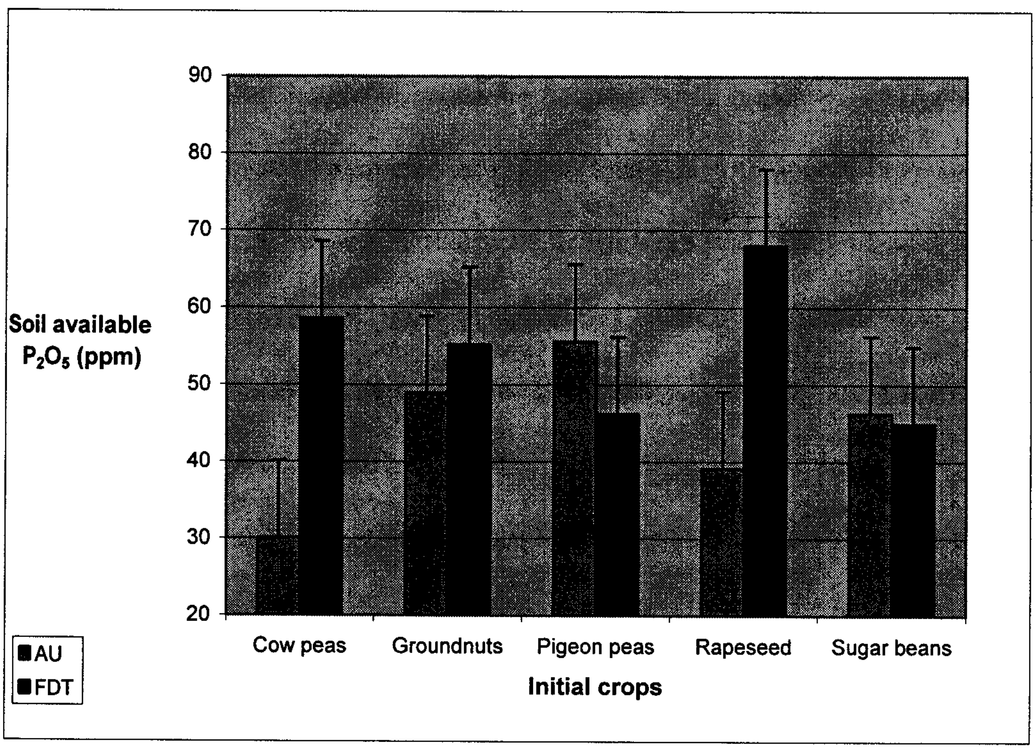

Figure 8 Soil available P_2O_5 after growth of different initial crops at AU and FDT field sites; 2006/2007 season

The higher soil available P_2O_5 after growth of groundnuts could be attributed to its rhizosphere activity which enhanced more DPR solubilization. Ponmurugan and Gopi (2006) reported a high density of phosphobacteria in the groundnut rhizosphere. Phosphate solubilising bacteria has been reported to increase PR dissolution (Supanjani *et al.*, 2006) and this could account for the higher soil available P_2O_5 in the groundnut rhizosphere. Ponmurugan and Gopi (2006) also reported of high phosphatase enzyme activity in the groundnut rhizosphere with the GP02 strain isolated from the groundnut rhizosphere soil having the highest activity when compared with strains from other crops. This could also have contributed to the high soil available P_2O_5 observed in groundnut rhizosphere.

The differences in performance of cow peas and pigeon peas at AU and FDT suggest that besides pH, soil type influences the release of P from DPR as mentioned in section 4.2.1.3. While pigeon peas can be grown in a wide range of soils, it grows best in well-drained medium heavy loams (New Forest projects, 2007) and thus AU soils would have been more suited for its optimum growth. Cow peas can also be grown on a wide range of well drained soils, but it is best suited to light sandy soils (Thomas Jefferson Agricultural Institute, 2007). This is evident in higher soil available P_2O_5 after cow peas in the sandy loam at FDT as well as in the greenhouse loamy sand soil (Section 4.2.1.3). Cow peas could have performed poorly at AU because the soil was a heavy sandy clay loam. Results suggest that soil type may influence growth and rhizosphere activities of different crops which could thus affect effectiveness of a crop in enhancing the release of P from DPR.

The high soil available P_2O_5 observed at FDT after rapeseed was probably enabled by rhizosphere modification. Chien (2001) reported that rapeseed exudation of citric and malic acid enhances PR effectiveness in soils with high pH.

4.3.2 pH after Initial crops

As indicated in table 4.12, there was significant interaction of initial crop and applied P_2O_5 on soil pH at AU ($P< 0.001$) and FDT ($P<0.01$). There were also significant differences in soil pH for the different rates of applied P_2O_5 at AU ($P<0.001$) and FDT ($P<0.01$). There were also significant difference in soil pH amongst the initial crops at FDT ($P<0.01$) and AU ($P<0.001$).

Table 4.12 Significance of F values from analysis of variance for soil pH after growth of initial crops at FDT and AU field site, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value	
		FDT	AU
Interaction of initial crop and DPR level on soil pH	48	**	***
Differences amongst initial crops on soil pH	4	**	***
Differences amongst applied P rates on soil pH	4	**	***

*** and** denotes significance at P= 0.001 and P= 0.01 respectively.

4.3.2.1 Effects of applied DPR rate on soil pH after different initial crops

There was significant interaction ($P<0.01$) between applied DPR rates and the different initial crops at FDT (Figure 9) and at AU (Figure 10). At FDT, there were no significant differences in pH amongst the different applied DPR rates for rapeseed. With pigeon peas, sugar beans and groundnuts, the lowest soil pH was observed in the control followed by an increase in pH as DPR rate increased from 0 to 40 kg/ha P_2O_5 at FDT (Figure 9). With pigeon peas and groundnuts there was a further increase in pH with increase of P level to 80 kg/ha P_2O_5 at FDT

There was however a drop in pH at 120 kg/ha P_2O_5 as DPR observed in all the legumes at FDT (Figure 9) and in rapeseed, pigeon peas and sugar beans at AU (figure 10).

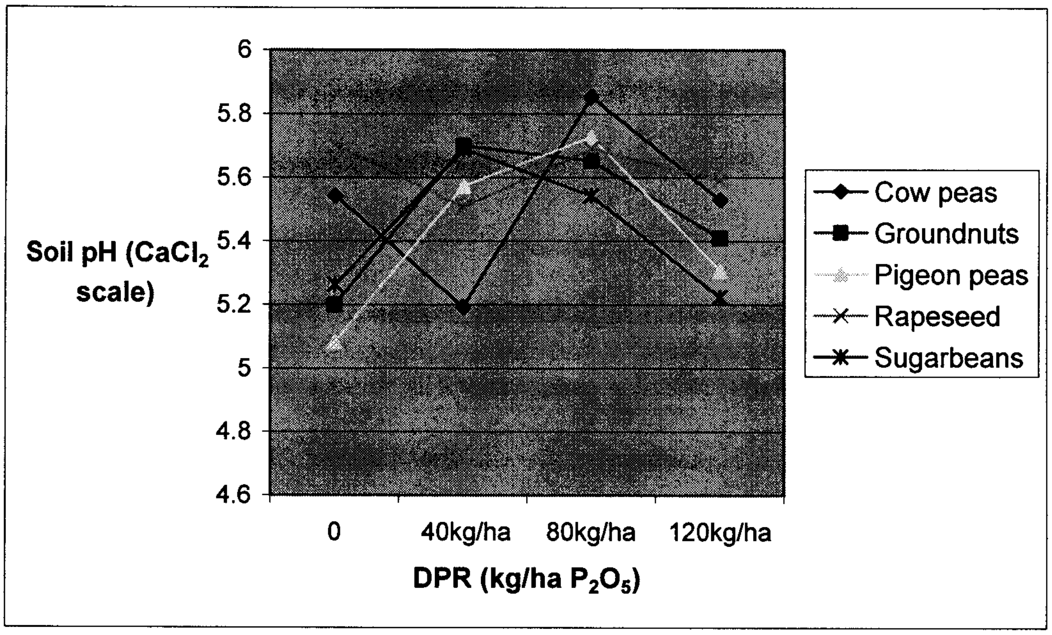

Figure 9 Effect of applied DPR and initial crop on soil pH after growth of initial crops at FDT, 2006/2007 season.

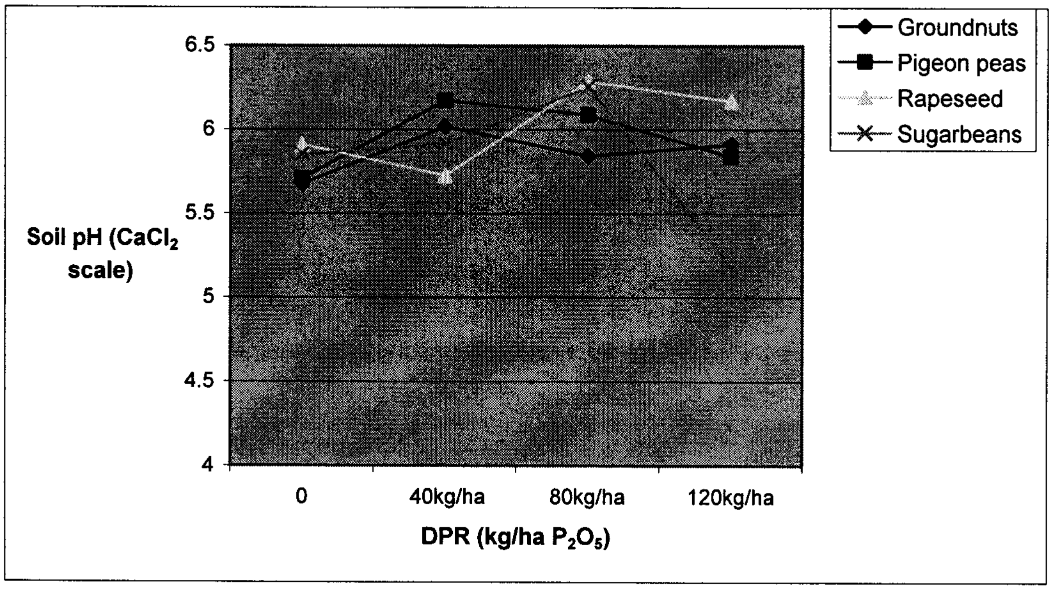

Figure 10 Effect of interaction applied DPR and initial crop on soil pH at AU, 2006/2007 season.

The increase in pH with increase in DPR rate observed in some of the initial crops at FDT and AU could be because as more DPR is dissolved more Ca is released into the soil thus the increase in pH as observed by Fagiya and Ma (2006) while using PR. The reasons for the drop in pH at 120 kg/ha P_2O_5 are not very clear.

4.3.2.2 Soil pH after growth of different crops

There were significant differences in pH amongst the different initial crops at FDT ($P<0.01$), and at AU ($P< 0.001$). Lower pH was observed after growth of legumes as compared to rapeseed (Figure 11). Compared with the other legumes, higher pH was observed after growth of cow peas. After growth of all the initial crops, soil pH at AU was higher than that at FDT.

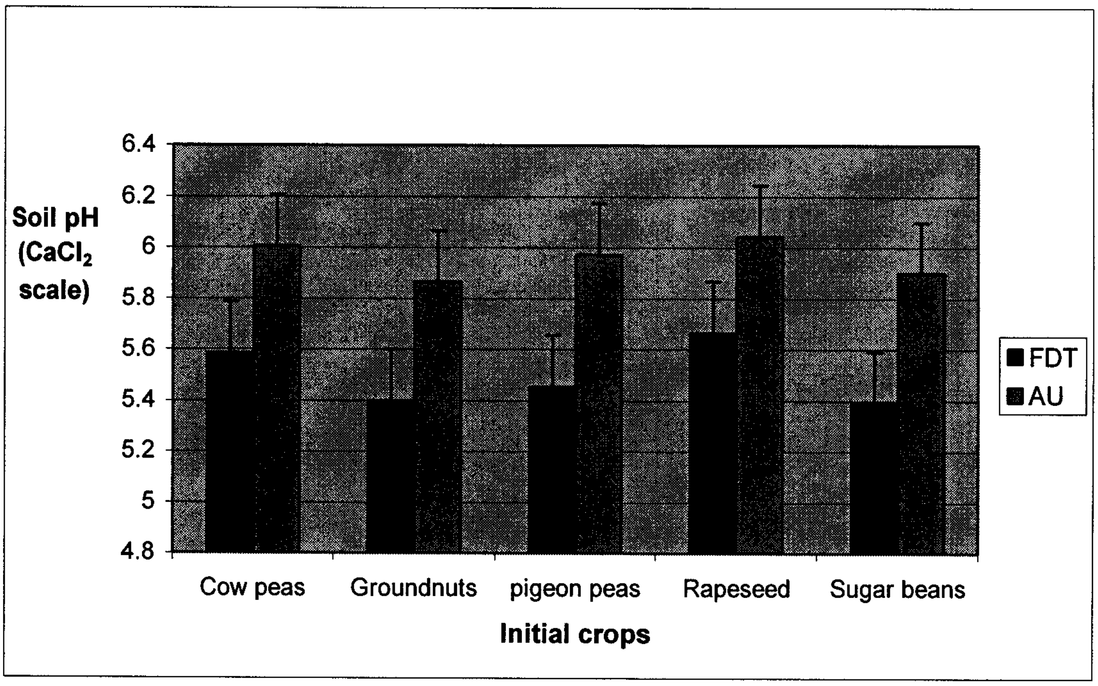

Figure 11 Soil pH after growth of initial crops at AU and FDT, 2006/2007 season.

The lower pH after growth of legumes could be attributed to their rhizosphere activity as alluded to in section 4.2.3.

4.3.2.3 Soil pH at different P_2O_5 levels

Significant differences were observed (Figure 12) amongst the different applied DPR levels in the soil pH after growth of initial crop at FDT ($P<0.05$), and at AU ($P<0.001$).

There was a rise in pH in all the AU plots by 0.079- 0.357 units from 5.74 observed at the beginning of the experiment (after liming). At FDT, there was a decrease in soil pH in all the plots by 0.157-0.491 from 5.85 at the beginning of the experiment. At AU and FDT, lower pH was observed in the control plots when compared with all the P fertilizer treatments. At both field sites, an increase in DPR level from 0 to 80 kg/ha P_2O_5 resulted in an increase in pH. A drop in pH was observed with increase in DPR level from 80 to 120 kg/ha P_2O_5 at both field sites. At FDT, the soil in which P had been added as DPR produced higher soil pH as compared to the soil in which P had been added as DSP (Figure12). At AU, there was no significant difference in pH at 120kg/ha P_2O_5 DPR and 80kg/ha P_2O_5 applied as DSP. The soil pH at 120kg/ha P_2O_5 DPR and 80kg/ha P_2O_5 DSP was lower than at the lower DPR rates.

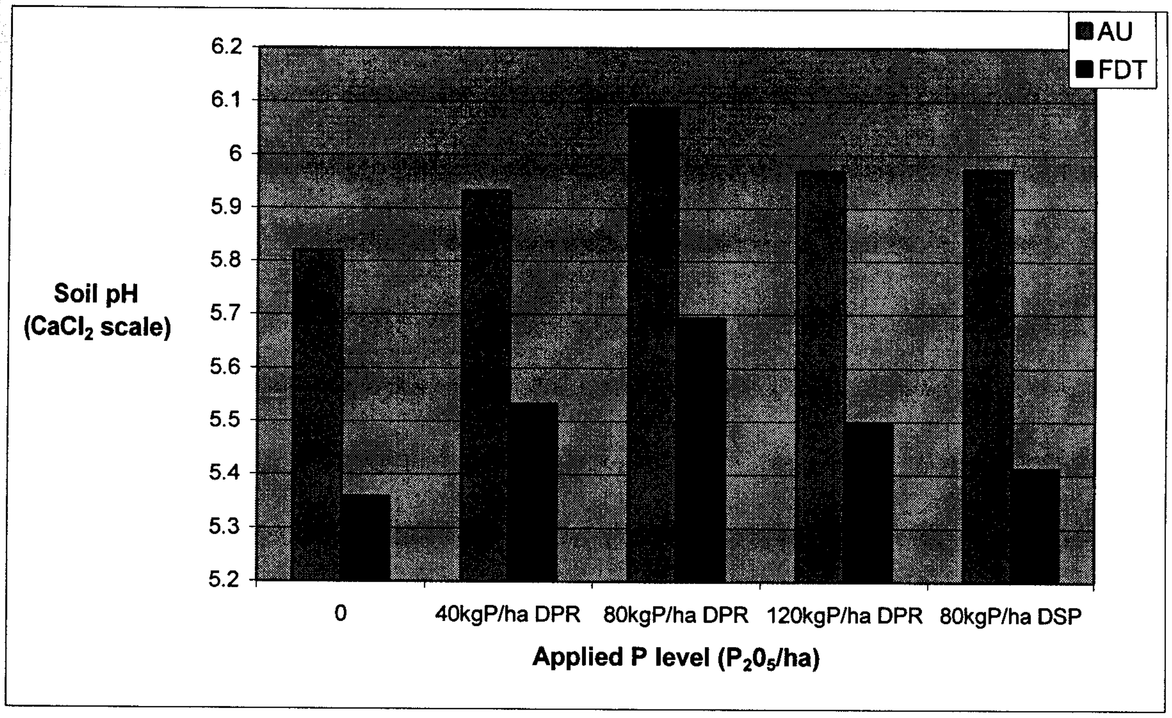

Figure 12 Soil pH after growth of initial crops fertilized at different applied P levels, 2006/2007 season.

The rise in pH at AU could be a result of Ca^{2+} release as observed by Fagiya and Ma (2006). The higher the DPR rate, the higher the available P_2O_5 observed (section4.3.1.2). This would also mean the higher the DPR dissolution, the higher the soil pH since more Ca^{2+} would have been released. This would account for the rise in pH at the two DPR rates (40 and 80 kg/ha P_2O_5) at AU. Similarly, in work done by Nekesa *et al.* (2005) on an acid Kenyan soil (pH 5.01), Minjingu PR was shown to effectively raise pH. It is not clear why there was a drop in pH at 120 kg/ha P_2O_5.

At FDT, there was no evidence of increase in available P_2O_5 where DPR had been applied (Section 4.3.1) thus it can be concluded that very little to no DPR dissolution took place. The drop in pH at all the FDT plots can be attributed to base depletion. Fagiya, Saha and Ma (2006) reported that there may still be a reduction in pH even where P is applied as PRs due to base depletion through nutrient uptake by plants. It is not clear why the pH dropped at 120kg/ha P_2O_5 at both sites, however, it could also be attributed to base depletion. It was only at 120kg/ha P_2O_5 where available P was above the critical point. Available P levels above the critical point may have promoted more efficient uptake of other bases thus more base depletion resulting in lower pH.

The lower pH observed where DSP had been applied could be due to its reaction in the soil. Super phosphates contain monocalcium phosphate which when dissolving, results in the formation of slowly soluble dicalcium phosphate (DCP) with a release of phosphoric acid close to the fertilizer granules, the phosphoric acid subsequently dissociated into P ions and acidic hydrogen ions, leading to a substantial decrease in soil pH as demonstrated by Bolan et al., (2003). This could be the reason for the lower pH observed in the soil fertilized with DSP in comparison to that fertilized with DPR. Even though the Zimbabwean manufactured super phosphate fertilizers have high Ca^{2+}, the net result of the monocalcium reaction and the high Ca^{2+} in DSP resulted in lower pH in the sandy FDT soil when compared to the sandy clay loam at AU. This may indicate that the reactions give different results under different soil conditions.

4.3.3 Nitrogen after growth of initial crops

There was no significant interaction ($P< 0.05$) between the type of initial crop and the applied P_2O_5 level in the amount of soil mineral nitrogen at both sites. There were also no significant differences ($P< 0.05$) amongst the different initial crops and applied P_2O_5 levels in the amount soil mineral nitrogen at AU and FDT. Amount of mineral nitrogen after growth of initial crops was less than that found originally in the soil before any planting was done at AU (63.4 ppm) and FDT (57.7 ppm).

Table 4.13 Significance of F values from analysis of variance of soil mineral nitrogen after growth of initial crops at FDT and AU field sites, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value	
		FDT	AU
Interaction of initial crop and DPR level on soil mineral N	48	NS	NS
Differences amongst initial crops on soil mineral N	4	NS	NS
Differences amongst DPR levels on soil mineral N	4	NS	NS

*** and** denotes significance at P= 0.001 and P=0.01 respectively.

It would have been expected to find a net increase in soil mineral nitrogen where legumes had been grown due to biological nitrogen fixation. However, there was a net decrease in soil mineral nitrogen at both field sites. Amount of soil available P_2O_5 from DPR at all field sites was not sufficient for growth of a following crop without supplementary P application (section 4.3.1). The low P status of the soil could also be the reason for the net decline in nitrogen after the legumes at both field sites. Graham and Vance (2003) reported that nodulation, N fixation and survival of rhizobia in soil are particularly affected under low P. Results from work done in Tanzania by Giller, Amijee, Brodrick and Edje (1998) also showed that in low P soils legumes can fix very little nitrogen.

However, the observed net decline in mineral N cannot be conclusive since the N was measured before incorporation of the initial crop's stover into the soil. Most legumes do not leave N in the soil but fix it into themselves and the N only becomes available from the legume when stover is returned to the soil and the stover decomposes. Giller (1991) reported that, where crop residues are removed, growing of certain legumes like soybeans may result in net loss of N.

4.3.4 Maize above ground biomass yield

There was significant interaction of initial crop and applied P_2O_5 on maize above ground biomass yield at AU ($P<0.05$) while there was no significant interaction observed at FDT ($P<0.05$) (Table 4.14). There were no significant differences ($P<0.05$) amongst the initial crops in maize biomass at both AU and FDT. There were significant differences amongst the applied P_2O_5 rates on maize biomass at AU ($P<0.01$) but there were no significant differences observed at FDT ($P<0.05$).

Table 4.14 Significance of F values from analysis of variance for maize above ground biomass yield at AU and FDT, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value	
		FDT	AU
Interaction of initial crop and applied DPR level on maize biomass	48	NS	*
Differences amongst initial crops on maize biomass	4	NS	NS
Differences amongst applied DPR level on maize biomass	4	NS	**

*** and** denotes significance at P= 0.001 and P=0.01 respectively.

4.3.4.1 Effect of applied P and initial crop on maize above ground biomass yield

Figure 13 shows the mean maize biomass after each initial crop at each applied DPR rate at FDT. At FDT no significant interaction ($P<0.05$) between initial crop and P levels was observed. At FDT site, the RAE of DPR with respect to DSP at 80 kg/ha P_2O_5 was 80%; 70.6%; 50%; 44%; and 33% for groundnuts, cowpeas, pigeon peas, rapeseed and sugar beans respectively.

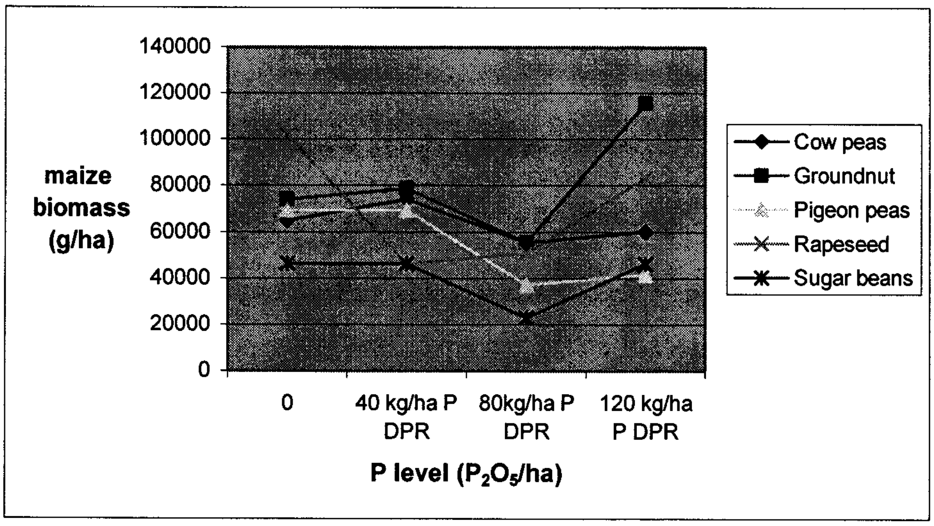

Figure 13 Maize above ground biomass yield after each initial crop at different applied DPR rates at FDT, 2006/2007 season.

Figure 14 shows above ground biomass yield at six weeks for maize grown after each initial crop at different applied P levels at AU. Significant interaction ($P<0.05$) of applied DPR and crops was observed at AU. The agronomic efficiency of the DPR combined with the initial crops with reference to DSP at 80kg/ha P_2O_5 at AU was 95%, 143%, 101%, 92% and 88% for cow peas, groundnuts, pigeon peas, and rapeseed and sugar beans respectively.

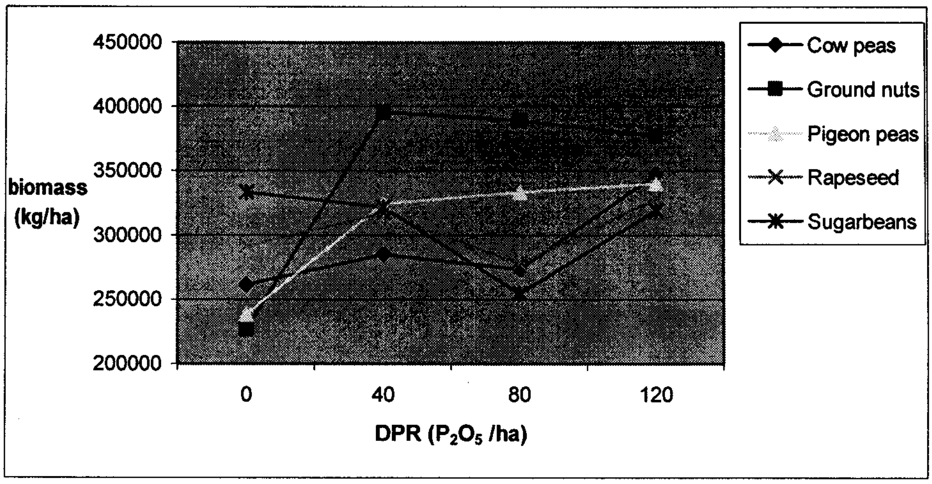

Figure 14. Effect of initial crop and applied DPR at AU on maize above ground biomass yield 6 weeks after emergence at AU, 2006/2007 season.

At AU, where maize followed sugar beans and rapeseed, there were no significant differences in biomass at different applied P_2O_5 levels (Table 4.14). Where maize followed cow peas, DPR at 80kgP_2O_5/ha was as good as the same rate of DSP in terms of maize biomass yield (Table 4.14). The highest biomass was achieved where maize followed groundnuts at the three DPR rates. In soil where maize followed groundnuts and pigeon peas, higher biomass was achieved with DPR as compared to the DSP fertilizer application (Table 4.14). The biomass of maize after groundnuts where P had been added as DSP was not significantly different from the control (Table 4.14).

Even though increasing DPR rate significantly increased soil available P_2O_5 at AU (Figure 9), it did not significantly increase the maize biomass where groundnuts and pigeon had been grown as initial crops (Table 4.14). At DPR and DSP application rates of 80 kg /ha P_2O_5, biomass of maize grown after cow peas was not significantly different (Table 4.14). At AU in soil where groundnuts and cowpeas had been grown, maize biomass did not significantly increase with further increase in DPR rates above 40kg/ha P_2O_5.

Table 4.15 Maize above ground biomass yield (g/ha) found after growth of legumes fertilized at different levels of DPR and DSP at AU, 2006/2007 season.

Initial Crop	Applied P_2O_5 (kg/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P value
Cow peas	261576	284725	273150	347225	287039	290743	**
Groundnuts	226854	395837	388892	377318	270836	331947	**
Pigeon peas	238428	324077	333336	340281	328706	312965	**
Rapeseed	291669	317132	277780	328706	300928	303243	**
Sugar beans	333336	321762	254632	319447	289354	303706	**
Mean	270373	328706	305558	342595	295373	308521	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

** denotes significance at P= 0.01. NS= not significant
CV 15.9%
L.S.D $_{(0.05)}$ 80649.9

The agronomic efficiency of DPR at AU was high (88-143%). Even though soil available P_2O_5 after growth of initial crops was higher where P had been applied as DSP (Table 4. 11), maize biomass was higher where DPR had been applied. Results show that the residual effect of P from DPR was higher than that of DSP. This is in agreement with observations by Singh et al. (2001) who reported the residual effect of Togo PR to be better than that of the soluble fertilizer TSP for a maize crop. The high agronomic efficiency of DPR in the maize biomass could be attributed to the long period of time over which the DPR was in the soil. Phosphate Rocks are reported to have higher agronomic efficiency in long season crops because of the continual release of P over time (Chien, 2001). Dorowa phosphate rock must have continued releasing P into the soil during the maize growing period.

4.3.4.2 Maize above ground biomass yield at the different applied DPR rates

Figure 15 shows the maize biomass at different applied P levels at AU and FDT. There were no significant differences (P= 0.05) in maize biomass amongst the different applied DPR rates at FDT. However, there were significant differences (P<0.01) in maize biomass amongst the different applied DPR rates at AU. Maize biomass was higher where P was applied as DPR at the DPR rates of 40, 80 and 120 kg P_2O_5/ha in comparison to P applied as DSP (Figure 15).

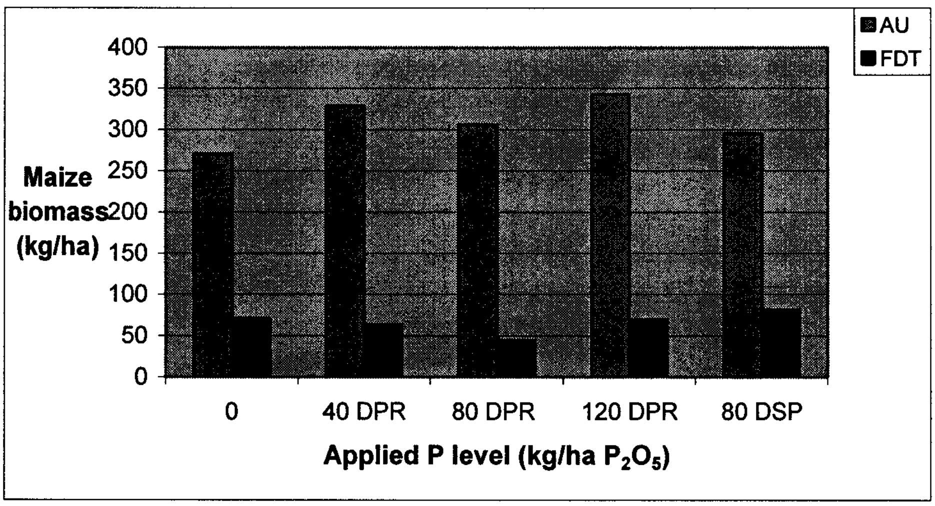

Figure 15 Above ground biomass yield of maize grown on residual P at 6 weeks at AU and FDT, 2006/2007 season.

Soil to which P was added as DSP may have had higher soil available P_2O_5 after harvest of the initial crop (Section 4.3.1.2) but the biomass of the subsequent maize crop in this sequence was higher where P was applied as DPR. These results show that DPR had a higher residual effect in supplying P to the subsequent maize crop as compared to DSP. This is in agreement with results from a study by Singh et al. (2001) who found that the residual effect of Togo PR was better than that of SSP when maize was used as the test crop. Results suggest that there could have been continual release of P from PR from the time of the initial crop into the growing season of the maize crop. This concurs with Chien (2001) who reported that more P is released from PRs over longer than shorter time periods.

4.3.4.3 Relationship between maize above ground biomass yield and soil pH after growth of initial crop

There was a strong positive correlation observed between soil pH after growth of initial crops and the maize biomass at 6 weeks (Figure 16).

Y= 6.944.5x + 2E-0.8

$R^2 = 1$

r = 1

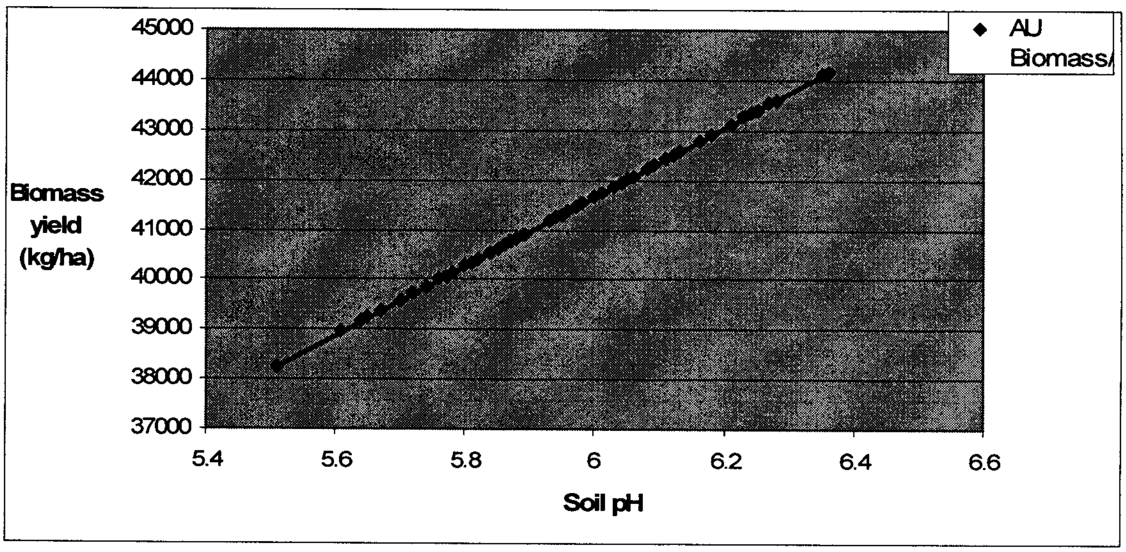

Figure 16 Correlation of biomass yield and soil pH at AU.

Fagiya and Ma (2006) reported that PRs may increase pH through the release of Ca^{2+} during their dissolution thus the more DPR solubilised, the higher the expected soil pH due to higher amount of Ca^{2+} released. Based on this, where higher pH was observed at AU, more DPR dissolution is expected to have taken place which would account for the higher maize biomass observed.

4.3.5 Maize grain yield

No significant interaction (P=0.05) was observed between the applied DPR rates and the different initial crops on the weight of 100 seeds at AU and FDT (Table 4.15). There were also no significant differences (P=0.05) amongst the P levels and the different initial crops in the weight of 100 maize seeds at AU and FDT (Table 4.15). There was no significant interaction (P=0.05) observed between initial crop and P level in the maize grain yield at AU and FDT (Table 4.15). There were also no significant differences (P=0.05) amongst the applied P levels and different initial crops in the maize grain yield at AU and FDT (Table 4.15).

Table 4.16 Significance of F values from analysis of variance for maize grain yield at AU and FDT, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value FDT	AU
Interaction of initial crop and applied DPR level on 100 seed counts	48	NS	NS
Differences amongst initial crops on 100 seed counts	4	NS	NS
Differences amongst applied DPR level on seed counts	4	NS	NS
Interaction of initial crop and applied DPR rate on maize grain yield (kg/ha)	48	NS	NS
Differences amongst initial crops on maize grain yield (kg/ha)	4	NS	NS
Differences amongst applied DPR level on maize grain yield (kg/ha)	4	NS	NS

NS= not significant at P= 0.05.

At FDT, there were no significant differences observed between the DPR rates in available P_2O_5 after initial crops (section 4.3.1). There were also no significant difference observed in maize biomass amongst the different DPR levels and initial crops. This resulted in no significant differences observed amongst the DPR levels and different initial crops in maize grain yeild. The weak response to DPR treatment in the FDT soil could be attributed to the high initial pH (5.85) which could have hindered DPR dissolution. This is in line with White and Johnson, (1980) who reported that no PR source was effective on soils having pH levels above 5.5-6.0. Fardeau (1997) also reported that replenishment of soil P fertility using phosphate rocks can be partly obtained in soils whose pH is lower than 5.8. During the course of the research, there was poor rainfall in the Nyamajura area thus moisture could have been a limiting factor thus contributing to the week response to both DPR and DSP at FDT. The high initial P (37.4 ppm) found in the FDT soil could also be a reason for the observed weak response to applied P.

The differences observed in soil available P_2O_5 (section4.3.1) and in maize biomass (section 4.3.4) at AU did not result in differences in maize grain yield. This could be attributed to the low reactivity nature of DPR. Similarly, Panda PR which is of low reactivity failed to significantly increase maize yields when used in direct application (Weil, 2000). The residual effect of DPR could be better with more successive seasons due to increased time for DPR dissolution. Bromfield, Hancock, and Debenham (1981) used Minjingu PR and found a nonsignificant 29% increase in maize (*Zea mays* L.) yield compared with the control in the first harvest after PR application, but there was a significant 73% increase in the third harvest. Contrary to this, studies by Ndung'u, Okalebo, Othieno, Kifuko, Kipkoech and Kimenye, (2005) in Kenya and Solla, Semoka, Szilas and Borggaard (2007) in Tanzania, application of

Minjingu PR resulted in increase in soil available P and subsequently higher maize grain yields.

5.0 CONCLUSION AND RECOMMENDATIONS

Results from the soil P analysis showed an increase in soil available P_2O_5 with increase in DPR rate in the AU field experiment and greenhouse experiment using Marange soil (initial pH of 5.01 and 4.8 respectively). At FDT (initial pH 5.85), there was no significant increase in soil available P_2O_5 with increase in DPR rate. The difference in available P between these soils seems to be related to the initial pH of the soils used. Marange and AU soils had lower pH than FDT soils. In high pH soils, use of more soluble P fertilizers maybe more preferable. However, DPR can improve P status of medium acid soils such as the Marange and the AU soils. The results also showed that critical levels of available P_2O_5 can be achieved at high DPR application rates. It is recommended to use DPR at higher application rates as compared to those used with soluble P fertilizer.

Results on maize biomass showed higher RAE of DPR with respect to DSP when compared to available P_2O_5 in all experiments. This shows that DPR has continual release of P and continued dissolution even after the growth period of the initial crop. It also shows that DPR was more efficient with the second crop when compared to the initial crop due to a difference in time allowed for dissolution. It is thus recommended to apply DPR to a preceding crop so as to maximize P availability for a succeeding crop. The differences in soil available P_2O_5 with increase in DPR rate did not result in differences in maize grain yield. At the rates of DPR used soil available P_2O_5 was inadequate for crop growth with no supplementary application. It is thus recommended to add P fertilizer if the residual soil available P_2O_5 is not adequate for crop production.

The ability of the initial crops to enhance DPR dissolution and hence improve P availability for a succeeding crop varied. From the greenhouse and AU field experiments, soil pH was lower after growth of legumes as compared to rapeseed. . It would thus be recommended to include legumes in crop sequences where there is direct DPR application so as to enhance dissolution due to their acidifying effect. Of all the legumes, soil pH in groundnut rhizosphere was the lowest and soil available P_2O_5 after initial crops was highest in soil in which groundnuts had been grown. This indicates groundnuts ability to acidify the rhizosphere thus enhancing P availability from DPR. Rapeseed showed superior performance in the FDT soil which had high initial pH (5.85) indicating it's potential to enhance P availability in soils of high pH. Performance of each of the initial crops in enhancing soil availability maybe influenced by soil conditions.

There was no grain yield response to applied DPR and DSP. This may indicate that there were other limiting factors and not P availability since application of DPR at 120 kg/ha and DSP at 80 kg/ha resulted in soil P levels adequate for crop growth. There is a need for more work to establish what these limiting factors could be. Additional field experiments need to be done to ascertain the residual effect of DPR application in cropping sequences over more cropping seasons (three or four). There is also need to evaluate DPR application rates higher than those used in this research. To further ascertain the dual effect of legumes improving soil N and P when used in crop sequences with DPR, more experiments need to be carried out where the initial legume crop is grown to full maturity and not incorporated as green manure as was done in this research. More work needs to be done to evaluate strategies of efficiently using DPR in direct application on soils of high pH such as that one found at FDT field site. More species both legume and non legume, can be analyzed for their potential in solubilising DPR in high pH soils when used in crop sequences.

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7.0 APPENDICES

Appendix 4.2.3 Effect of initial crop and applied P fertilizer on soil pH in the greenhouse, 2006/2007 season.

Crop	P level (P_2O_5) 0	40 kg/ha (DPR)	80 kg/ha (DPR)	120 kg/ha (DPR)	80 kg/ha (DSP)	Mean	P value
Cow peas	5.710	6.11	5.91	5.99	5.73	5.89	***
Groundnuts	5.64	5.79	5.77	5.90	5.53	5.73	***
Pigeon peas	5.65	5.78	5.87	5.99	5.90	5.84	***
Rapeseed	5.89	6.13	6.14	6.16	6.19	6.10	***
Sugar beans	5.69	5.68	5.85	5.78	5.82	5.76	***
Mean	5.71	5.90	5.91	5.96	5.83	5.86	
$P^{(0.05)}$	***	***	***	***	***		

*** denotes significance at P= 0.001.
CV 2.6%
$LSD_{0.05}$ 0.2543

Appendix 4.3.3a Mineral nitrogen (ppm) after growth of legumes at AU, 2006/2007 season.

Initial Crop	Applied P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P
Cow peas	39.16	41.45	41.00	44.44	49.75	43.16	NS
Ground nuts	33.03	43.84	43.99	42.14	36.73	39.95	NS
Pigeon peas	41.71	33.00	38.27	38.16	41.75	38.58	NS
Rapeseed	40.44	40.39	35.05	36.18	35.77	37.56	NS
Sugar beans	41.00	36.81	37.22	39.58	37.75	38.47	NS
Mean	39.07	39.10	39.11	40.10	40.35	39.54	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant (P= 0.05)
CV% 18.2

Appendix 4.3.3b Mineral nitrogen (ppm) after growth of legumes at FDT, 2006/2007 season.

Initial Crop	Applied P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P
Cow peas	33.7	40.9	40.0	33.7	45.4	43.16	NS
Ground nuts	38.0	40.5	41.3	30.3	33.2	39.95	NS
Pigeon peas	50.8	35.2	32.0	31.5	46.0	38.58	NS
Rapeseed	41.4	41.8	30.9	34.2	28.1	37.56	NS
Sugar beans	42.5	40.1	36.0	37.1	37.4	38.47	NS
Mean	41.3	39.7	36.0	33.4	38.0	37.7	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant (P= 0.05)
CV% 24.1

Appendix 4.3.5a Weight of 100 seeds (g) after different initial crops and applied P levels at AU

Initial Crop	P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	
Cow peas	42.22	42.02	42.52	42.32	43.39	42.49	NS
Ground nuts	43.69	40.67	41.95	39.29	42.07	41.53	NS
Pigeon peas	46.20	42.62	40.00	44.04	42.07	42.99	NS
Rapeseed	44.14	40.09	44.42	42.63	44.73	43.20	NS
Sugar beans	38.30	42.58	40.95	43.29	43.70	41.76	NS
Mean	42.91	41.60	41.97	42.32	43.19	42.40	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant (P=0.05)
CV 6.1%

Appendix 4.3.5b Weight of 100 seeds (g) after different initial crops and P levels at FDT

Initial Crop	P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P
Cow peas	35.11	32.60	31.64	33.13	32.09	32.91	NS
Ground nuts	33.60	31.68	30.30	32.82	29.50	31.58	NS
Pigeon peas	32.56	33.35	31.60	29.35	31.90	31.75	NS
Rapeseed	29.63	32.08	26.72	33.31	33.85	31.12	NS
Sugar beans	28.13	30.95	31.58	29.70	31.08	30.29	NS
Mean	31.80	32.13	30.37	31.66	31.68	31.53	
$P^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant (P= 0.05)
CV% 8.2

Table 4.3.5c Maize grain yield (kg/ha) after different initial crops and P levels at AU

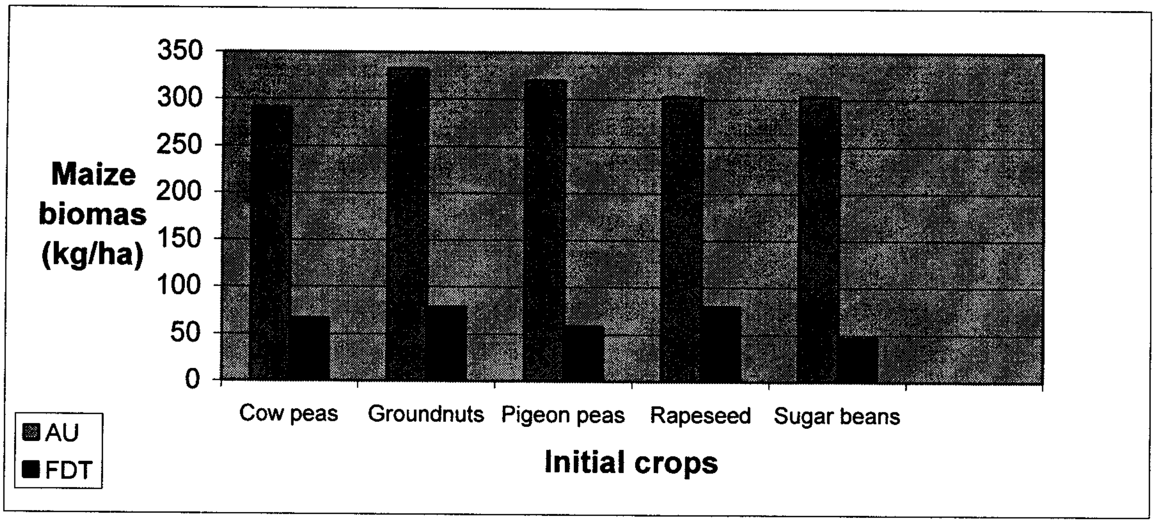
Initial Crop	P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P
Cow peas	5577	5070	5558	5078	5618	5380	NS
Ground nuts	4963	5304	5277	4677	5320	5108	NS
Pigeon peas	5595	5458	4798	5598	5093	5308	NS
Rapeseed	5673	5449	4508	4690	4863	5037	NS
Sugar beans	5114	5035	5053	5131	4665	5000	NS
Mean	5384	5263	5039	5035	5112	5167	
P $^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant (P= 0.05)
CV% 13.7

Table 4.3.5d Maize grain yield (kg/ha) after different initial crops and P levels at FDT

Initial Crop	P level (kg P_2O_5/ha)						
	0	40 DPR	80 DPR	120 DPR	80 DSP	Mean	P
Cow peas	3198	2214	2510	3199	2443	2713	NS
Ground nuts	2884	3442	2499	3148	2427	2880	NS
Pigeon peas	2645	2738	3194	2030	2634	2648	NS
Rapeseed	2266	2957	2252	3012	3044	2706	NS
Sugar beans	2289	2229	2625	2600	2656	2480	NS
Mean	2657	2716	2616	2798	2641	2685	
P $^{(0.05)}$	NS	NS	NS	NS	NS		

NS= not significant ($P<0.05$)
CV% 21.8



Appendix 4.3.4.2 Maize biomass after each initial crop at AU and FDT, 2006/2007 season.