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Dorowa Phosphate Rock (DPR) as a source of available Phosphorus for Maize (*Zea mays*) crop under different crop sequences

[1]Itai Mutukwa and [2*]Fanuel Tagwira
Africa University, Mutare, Zimbabwe.

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Corresponding Author:
Fanuel Tagwira
Africa University,
Mutare, Zimbabwe.

Abstract
An experiment was conducted in the field to assess the effect of crop sequencing on effectiveness of dorowa phosphate rock (dpr) as a source of p for the following maize crop.. Sugar beans (phaseolus vulgaris), groundnuts (arachis hypogaea), rapeseed (brassica napus), cow peas (vigna unguiculata) and pigeon peas (cajanus cajan) were selected for the study. The crops were combined factorially with five p_2o_5 levels ; 0, 40, 80 and 120 kg/ha p_2o_5 to give 25 treatments. The treatments were replicated three times to give 75 plots which were implemented at au and fdt sites. The initial crops were harvested after six weeks and their stover was turned in (except for rapeseed). A maize crop was grown to maturity in the same soils using the residual phosphate. Agronomic records were collected for the initial crop and the maize crop. Significant difference ($p<0.05$) were observed in mean available p_2o_5 for the soils to which different initial crops were grown at both sites. Also, significant differences ($p<0.001$) in available p_2o_5 at different rates of applied p_2o_5 at au and fdt were observed. The results from au site showed that 120kg/ha dpr will give available p above 30ppm (mehlich p), which is needed to sustain a good subsequent maize crop according to jones and piha (1989). Rape seed and cowpeas performed best at fdt while pigeon peas and groundnuts performed best at au site. The differences in performance of the initial crops in the two different soils may be related to soil type, initial fertility or rhizosphere activity on phosphate dissolution. Significant interaction between initial crop and applied p_2o_5 on maize biomass was observed at au site. At fdt 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. 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. There was a strong correlation observed between soil ph after growth of initial crops and the biomass of the subsequent maize crop at a.u. site. The differences observed in soil available p_2o_5 and in maize biomass at au did not translate into differences in maize grain yield. Other factors other than available phosphate were concluded to be responsible.

Key words: ***P****hosphorus, Dorowa Phosphate Rock (DPR), Crop sequencing, Groundnuts, Rapeseed, Residual fertility.*

Introduction

Crop yield on most Zimbabwean soils are limited by low phosphorus availability as the country suffers from declining soil fertility (Chibudu, Chiota, Kandrios, Mavendzenge, Mombeshora, Mudhara, Murimbarimba, Nasasara, and Scoones, 2001). Smallholder farmers use manure to improve their soil fertility but research has shown that most smallholder sector manure is low in phosphorus (Chikowo, Tagwira and Piha, 1999)

The locally produced phosphate fertilizer from the Dorowa Phosphate Rock (DPR) is beyond the reach of the smallholder farmers. Unprocessed DPR is an inexpensive source of phosphorus with long term residual effects that can contribute to recapitalization of P in soils. However, if directly applied, DPR does not produce the desired short-term outcomes due to its low P solubility (Govere, Chien and Fox, 2005; Dhliwayo, 1999). Finding a way to improve solubility of the unprocessed rock would help reduce the cost of phosphorus input into the smallholder farming system. To produce short term benefits the DPR must be modified to enhance its solubility in order 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 organic acids, and decreasing particle size (Goenadi, 1990, Govere and Chien, 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 have also been shown to vary with crop species (Chien, Sale, and Hammond, 1990). Some crops have been shown to be better at improving PR dissolution than others and thus a following crop may benefit from P released from PR by the first crop. Some of the crop factors that have been observed to increase solubility are: P demand, calcium absorption, exudation of acidic compounds to the rhizosphere, rooting density and type of growth cycle (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 allow 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).

The aim of this research was to test the potential of various crops to solubilize P from DPR for the subsequent field maize crop. Among these crops are legumes which could also contribute soil nitrogen through biological nitrogen fixation, thereby giving a double benefit. The objective of the study was to assess the effect of crop sequence on DPR phosphate availability and yield of the following maize crop.

Materials and methods

A field experiment was conducted to evaluate the effect of crop sequence on the availability of P for the following maize crop when DPR was used as the P source for a previous crop. The experiments were conducted at two sites: Farmers Development Trust farm (FDT) in Nyamajura (18^{o}52' S: 32^{o}26' E) and Africa University farm (AU) in Old Mutare (18^{o}89' S: 32^{o}60' E). Both sites are in Manicaland Province of Zimbabwe. The soil at FDT was an alfisol (USDA Classification) derived from granite parent material while that at Africa University the soil was a oxic haplustalf derived from mafic rock (Nyamapfene, 1991). Both soils are highly leached with mostly 1:1 layer silicates and sesquioxides. Both experimental sites have unimodal rainfall pattern and mean annual temperature of 22^{o}C. . The FDT site receives about 450 to 550 mm of rain annually while the Africa University site receives about 700 to 800mm annually. The rainfall is received between November and March. The elevation of the experimental sites is between 900 and 980m above sea level.

Sugar beans (*Phaseolus vulgaris*), groundnuts (*Arachis hypogaea*), rapeseed (*Brassica napus*), cow peas (*Vigna unguiculata*) and pigeon peas (*Cajanus cajan*) were selected for the study. The crops were combined factorially with five P_2O_5 levels ; 0, 40, 80 and 120 kg/ha P_2O_5 to give 25 treatments. The treatments were replicated three times to give 75 plots. Potassium was added at the rate of 60kg/ha of K_2O. To the legume crops, starter nitrogen at a rate of 50 kgN per hectare was applied in the form of AN. The initial crops were harvested after six 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 phosphate. To the maize crop, nitrogen in the form of AN was applied at a rate of 200 kgN/ha. The AN application was split into 3 applications (36 kgN/ha applied at planting, 82 kg N/ha at six weeks and another 82 kg N/ha at tasseling). Groundnut, sugar beans, cowpeas rapeseed and pigeon pea agronomic records collected were: germination percentage, plant stand, disease incidence, rainfall and biomass. Maize agronomic records collected were: germination percentage, plant stand, disease incidence, rainfall, yield, biomass, kernel size, 100 seed weight and P uptake.

The soil used was characterized before the experiment was carried out. The soil was analyzed for pH using 0.01M$CaCl_2$ methods. Available P and exchangeable K, Ca, Mg, and Cu in the soil were extracted using Mehlich 3 solution (Mehlich, 1984). The P was determined using the Murphy and Riley method (Murphy and Riley, 1962), while K, Ca, Mg, and Cu were determined using the Varian Atomic Absorption Spectrophotometer. Statistical analysis was done using analysis of variance and the least square significance difference (LSD) method was used to separate means using Genstat for Windows Discovery Edition 2 and 7.2 release packages. Treatment means were compared at probability $P<0.05$. .

Results and Discussion

Soil Characterization

T able 1 shows the initial chemical and physical characteristics of AU and FDT soil used in the field. The two soils had low pH. The AU soil had available P_2O_5 below 30ppm P_2O_5 (Mehlich 3 extractable) established by Jones and Piha (1989) as the critical level for these Zimbabwean soils.

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). Significant difference in available P_2O_5 for the soils to which different initial crops were grown at FDT ($P<0.05$) and AU ($P<0.001$)

were observed. Also significant differences ($P<0.001$) in available P_2O_5 at different rates of applied P_2O_5 at AU and FDT were observed.

Table 1. Chemical and physical characteristics of soils used in field experiments.

Analysis Description	AU Soil	FDT Soil
Soil Texture	Sandy Clay Loam	Sandy Loam
Soil pH	5.01	5.85
Available phosphorus (ppm)	17.8	37.4
Exchangeable potassium (me%)	0.63	0.18
Exchangeable Calcium (me%)	8.58	1.19
Exchangeable Magnesium (me%)	5.20	0.82
Available Copper	1.42	1.19

Table 2. 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	FDT
Interaction of initial crop and DPR rate on soil available P_2O_5	48	NS	NS
Differences amongst initial crops on soil available P_2O_5	4	*	***
Differences amongst DPR rates 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*

Significant differences in mean available P in soils to which the different initial crops were grown at both sites (Table 3) were observed. Different rates of applied DPR at Africa University site gave significant differences in available phosphate (Fig 1).

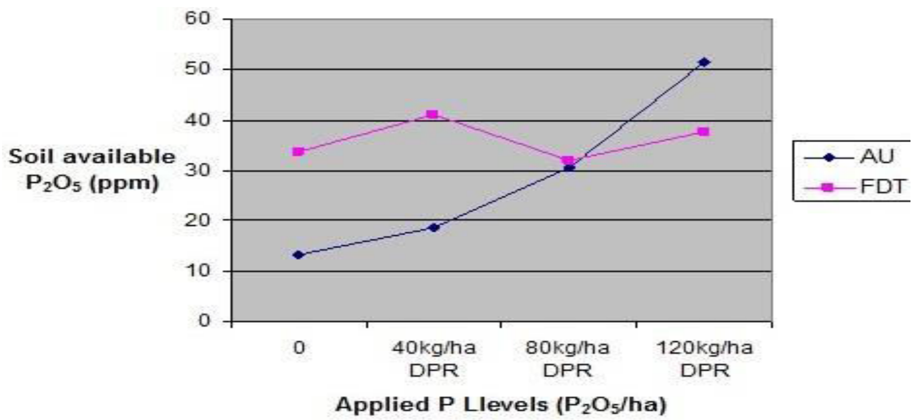

Fig 1. Soil available P_2O_5 at different applied DPR rates at AU and at FD T , 2006/2007 season.

The lack of response to different DPR rates at FDT could be a result of the high initial soil pH of 5.85 (0.01M $CaCl_2$) which could have negatively affected solubility of DPR applied at the different rates. White and Johnson, (1980) reported that no PR source was effective on soils having pH levels above 5.5. 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. At FDT, there was also high initial P (37.4 ppm) which could have affected DPR dissolution. Based on law of mass action (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 120kg/ha DPR will give available P above 30ppm, which is needed to sustain a good subsequent maize crop. Jones and Piha (1989) established that 30ppm available P_2O_5 (Mehlich 3 extractable) was the critical level for these Zimbabwean soils. In the FDT soil the highest available P_2O_5 was found after growth of rapeseed followed by cowpeas (Figure 2) while at AU site it was pigeon peas followed by groundnuts.

Table 3. Mean soil available P_2O_5 after growth of each initial crop fertilized with different levels of DPR and DSP at AU and FDT.

Crops	Available Soil P2O5 (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.*

The differences in performance of the initial crops in the two different soils may indicate that soil type, initial fertility or rhizosphere activity may have an effect on phosphate dissolution in the soil. While pigeon peas can be grown in a wide range of soils, it grows best in well-drained medium heavy loams 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. 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.

Maize (Zea mays L.) biomass

There was significant interaction of initial crop and applied P_2O_5 on maize biomass at AU (P<0.05) but not at FDT (Table 4). There were no significant differences (P<0.05) amongst the initial crops in maize biomass at both AU and FDT but there was significant (P< 0.01) differences amongst the applied P_2O_5 rates on maize biomass at AU site.

Table 4. Significance of F values from analysis of variance for maize biomass at AU and FDT, 2006/2007 season.

Variate	Degrees of freedom	Significance of F value	
		FDT	AU
Interaction of initial crop and DPR rates 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.*

At FDT the relative agronomic effectiveness (RAE) of DPR with respect to DSP at 80 kg/ha P_2O_5 was 80%; 70.6%; 50%; 44%; and 33% for plots previously cropped with groundnuts, cowpeas, pigeon peas, rapeseed and sugar beans respectively (Fig 2). At AU the agronomic efficiency of the DPR with reference to DSP at 80kg/ha P_2O_5 at AU was 95%, 143%, 101%, 92% and 88% for plots previously crop with cow peas, groundnuts, pigeon peas, and rapeseed and sugar beans respectively (Fig 3).

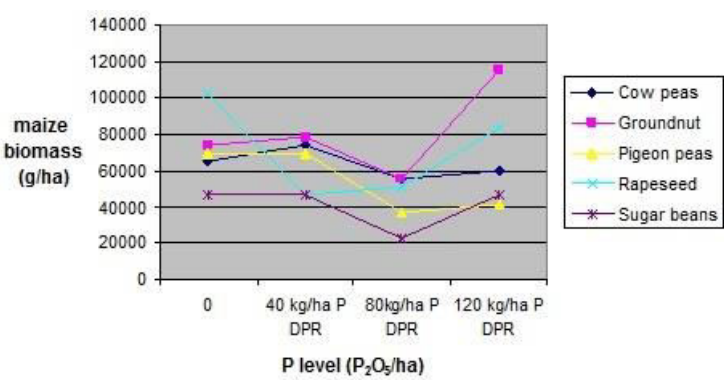

Fig 2. Maize biomass after each initial crop at different applied DPR rates at FDT, 2006/2007 season.

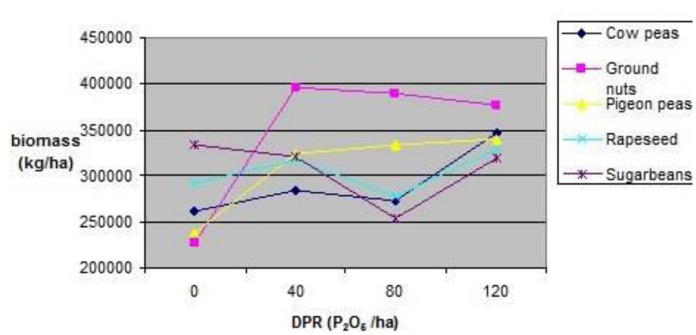

Fig 3. Effect of initial crop and applied DPR at AU in maize biomass 8 weeks after emergence at AU, 2006/2007 season.

Maize biomass at the different applied DPR rates

There were no significant differences (P= 0.05) in maize biomass amongst the different applied DPR rates at FDT (Fig 5). However, there were significant differences (P<0.01) in maize biomass amongst the different applied DPR rates at AU.

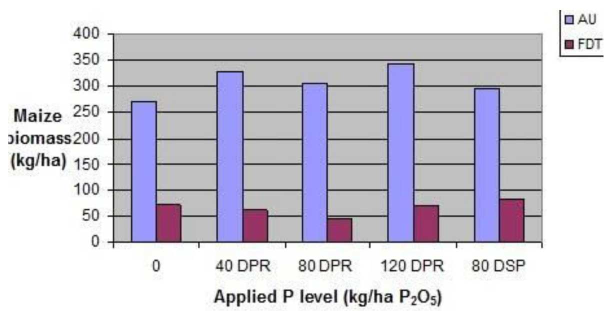

Fig. 4 Biomass of maize grown on residual P at 8 weeks at AU and FDT, 2006/2007 season.

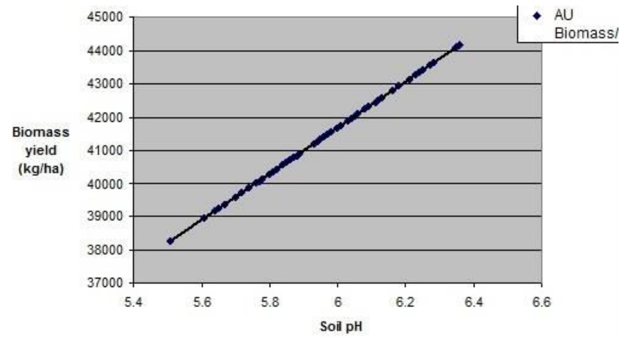

Fig 5. Correlation of biomass yield and soil pH at AU.

There was a strong correlation observed between soil pH after growth of initial crops and the biomass of the subsequent maize crop (Fig. 6) at A.U. site.

Y= 6.944.5x + 2E-0.8
$R^2 = 1$

Fagiya and Ma (2006) reported that PRs may increase pH through the release of Ca^{2+} during their dissolution thus the more DPR solubilized, 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.

Maize (Zea mays L.) grain yield

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 5). There were also no significant differences (P=0.05) amongst the applied P levels and different initial crops on maize grain yield at AU and FDT (Table 5).

Table 5. 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 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.

The differences observed in soil available P_2O_5 and in maize biomass at AU did not translate into differences in maize grain yield. Other factors other than available phosphate could be responsible. Using Minjingu PR, Bromfield, Hancock, and Debenham (1981) found no response to 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. On the other hand, in another study by Ndung'u, Okalebo, Othieno, Kifuko, Kipkoech and Kimenye, (2005) in Kenya and Solla, Semoka, Szilas and Borggaard in Tanzania (2007), application of Minjingu PR resulted in increase in soil available P and maize grain yields in the year of application.

Conclusion and Recommendations

Results showed an increase in soil available P_2O_5 with increase in DPR rate in the AU site and not at FDT. The intial pH may have been a factor since AU soil had lower initial pH than FDT soils. In high pH soils, use of soluble P fertilizers maybe more preferable.

The results also showed that critical levels of available P_2O_5 (30ppm) can be achieved at DPR application rate of 120kg/ha P_2O_5. It is therefore recommended to use DPR at higher application rates as as this can substitute for processed fertilizer use.

Results on maize biomass showed high RAE of DPR when compared to DSP. Maize biomass response to DPR was observed at AU site but not at FDT. However the responses observed in available P and biomass at AU did not translate into increased maize grain yields. The ability of the initial crops to enhance DPR dissolution and hence improve P availability for a succeeding crop was observed for the various crops. Even though this did not translate in increase in yield of subsequent maize crop, the fact that legumes increased available P is an important indicator that including legumes in a crop sequence where DPR is applied will result in increase of available phosphate which can be utilized by the cereal crop in the sequence. The added benefit is that the legume crop will also add nitrogen which can be utilized by the cereal crop in the rotation. The lack of grain yield response to increased available phosphate may be due to other factors like moisture quantity which was low since DSP also did not result in increased yield. Additional field experiments need to be done to ascertain the residual effect of DPR application in cropping sequences over more cropping seasons than was possible in this research. 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.

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