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# Agronomic effectiveness of unacidulated and partially acidulated Minjingu rockphosphates on *Stylosanthes guianensis*

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## Abstract

The majority of soils in Africa are P-deficient, but the high cost of conventional, water-soluble P fertilisers limits their use by resource-poor farmers. Rockphosphates are a low-cost alternative. The relative agronomic effectiveness of unacidulated (RP), 25% partially acidulated (PARP25), 50% partially acidulated (PARP50) Minjingu rockphosphate and triple superphosphate (TSP) was evaluated at rates of 0–80 kg/ha P on stylo (*Stylosanthes guianensis*) on an Ultisol in the Ethiopian highlands. The fertilisers were applied once and their effects were followed for 4 consecutive harvests. Stylo dry matter (DM) yields were below 3 t/ha at each cut without applied P and reached as high as 4.8 t/ha when P was applied. Over all 4 cuts, RP was 100%, PARP25 was 89% and PARP50 was 103% as effective as TSP in increasing stylo herbage yields. The corresponding relative responses in P uptake were 103, 79 and 92% for RP, PARP25 and PARP50, respectively. The substitution rates for herbage yields were 100% for RP, 79% for PARP25 and 106% for PARP50 while those for P uptake were 106% for RP, 62% for PARP25 and 85% for PARP50. Significant ($P < 0.05$) effects of P on stylo DM and P uptake were observed at all harvests. It is concluded that raw Minjingu rockphosphate is highly effective on stylo in these soils. This rockphosphate could be used to increase forage production for increased and sustainable crop-livestock productivity on the P-deficient Ultisols.

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## Introduction

Most soils in sub-Saharan Africa (SSA) are so deficient in P that, without additional P, the impact of other agricultural technologies is limited (Sanchez *et al.* 1997). However, the high cost of conventional, water-soluble P fertilisers limits their use by resource-poor farmers. Application of rockphosphates is a low-cost alternative where indigenous deposits are available. In recognition of the P-deficiency problem, the World Bank has considered supporting agricultural development in SSA through investment in the replenishment of soil P using local rockphosphate sources (World Bank 1994).

Studies on rockphosphates in SSA have been conducted mostly on food crops (Sale and Mokwunye 1993). Data on forage crops is scarce. Studies on pastures in Australia and New Zealand have produced contrasting results. Field studies in New Zealand showed that rockphosphates can be as effective as soluble P fertilisers, but similar studies in Western Australia indicated that rockphosphates are ineffective because of limited dissolution (Bolan *et al.* 1990). In the Ethiopian highlands, Egyptian and Togo rockphosphates were found to be 82–92% and 54%, respectively, as effective as triple superphosphate in increasing herbage yields of African clovers (*Trifolium* spp.) (Haque and Lupwayi 1998a; 1998b).

When the effectiveness of raw rockphosphate is limited by low reactivity, partial acidulation can be used to increase its solubility. Partial acidulation is a process where rockphosphate is treated with only a portion of the sulphuric acid and/or phosphoric acid required to produce single superphosphate or triple superphosphate (Hammond *et al.* 1986). Both acidulated and partially acidulated Minjingu rockphosphates have been found to be highly effective (107–114% as effective as triple superphosphate) in increasing clover yields in the Ethiopian highlands (Haque *et al.* 1999). In this work, we report the results of field evaluation of unacidulated and partially acidulated Minjingu rockphosphate on stylo (*Stylosanthes guianensis*) grown on an Ultisol in the Ethiopian highlands.

## Materials and methods

The experiment was conducted on a highland Ultisol deficient in P (Bray II P: 0.23 μg/g soil; pH 5.0 in $H_2O$) at the International Livestock Research Institute (ILRI) experimental research farm at Soddo (1950 m above sea level; 837 mm annual rainfall; and 19° C mean annual temperature). Unacidulated Minjingu rockphosphate (RP), 25% partially acidulated rockphosphate (PARP25), 50% partially acidulated rockphosphate (PARP50) and triple superphosphate (TSP) fertilisers were applied to 3 m × 3 m plots once at 0, 20, 40, 60, 80 and 100 kg/ha P. Minjingu phosphate rock is a sedimentary deposit mined in Tanzania, with 10.9% citrate-soluble P and 38.8% CaO, but the marketed product after dry separation contains 12–13% P (van Kauwenbergh 1991). The treatments were replicated 3 times in a split-plot randomised complete block design in which P sources were main plots and P rates were sub-plots. The fertilisers were broadcast on the plots and incorporated into the soil on July 5, 1989. Stylo (*Stylosanthes guianensis* cv. Cook) was sown on August 7, 1989 in rows 25 cm apart at a seeding rate of 5 kg/ha. Plants were cut from 2 m × 2 m net plots on January 26, 1990, and regrowth was cut on April 25, August 14 and November 13, 1990 for estimation of herbage dry matter (DM). At each harvest, the herbage was analysed for N and P (Tekalign Tadesse *et al.* 1991) to estimate N and P uptake by multiplying the concentrations of these nutrients in the herbage by the DM yields.

Analysis of variance was performed on the DM, P-uptake and N-uptake data at each harvest and the means were separated by least significant difference (LSD) tests using MSTAT-C computer software (Michigan State University 1988). The cumulative responses of stylo DM and P uptake to P rate were determined and were best described by the following equation (Chien *et al.* 1990):

$$Y_i = Y_0 + b_i \sqrt{\text{P rate}} \quad (1)$$

where $Y_i$ = DM (or P) yield obtained with source (i), $Y_0$ = DM (or P) yield obtained with no added P, $b_i$ = regression coefficient of source (i), and P rate = rate of P applied.

The effectiveness of each rockphosphate relative to TSP was assessed in 3 ways: (a) relative yield response (RYR) index; (b) substitution rate (SR); and (c) linear response comparison (Chien *et al*. 1990). RYR and SR were calculated from the regression coefficients of the fitted response curves (Equation 1) as follows:-

$$\text{RYR (\%)} = (b_i / b_{TSP}) \times 100 \quad (2)$$

$$\text{SR (\%)} = (\text{RYR})^2 / 100 \quad (3)$$

Equation 3 applies only for the response curve described by Equation 1. The linear responses of DM and P uptake were determined for application rates of 0–40 kg/ha P. The regression coefficients of the fitted lines were then used to calculate RYR using Equation 2. In the linear response comparison, RYR = SR.

## Results

### *Responses to P over time*

Stylo DM yields in control plots at the 4 cuts following application of P ranged from 2.91 to 1.87 t/ha (Figures 1a-e). Yields with applied P were as high as 4.8 t/ha (Figure 1d).

All P sources at all application rates significantly (P<0.05) increased DM yields over the control at all cuts (Figures 1a-d), with little differences between P sources.

Responses in P uptake and N uptake to applied P were similar to the responses in DM described above, except that responses in P uptake at 20 kg/ha P were less pronounced than responses at higher rates (P- and N-uptake data not presented).

### *Overall response to P and relative effectiveness of the rockphosphates*

The cumulative response curves for DM yield (Figure 2a) and P uptake (Figure 2b) show that DM yields and P uptake were still increasing at 100 kg/ha P. The curves also show that relative yield responses of stylo DM to all P sources were high: 103% for PARP50; 89% for PARP25; and 100% for RP (Table 1). The corresponding substitution rates were 106, 79 and 100%. With regard to P uptake, responses to the P sources

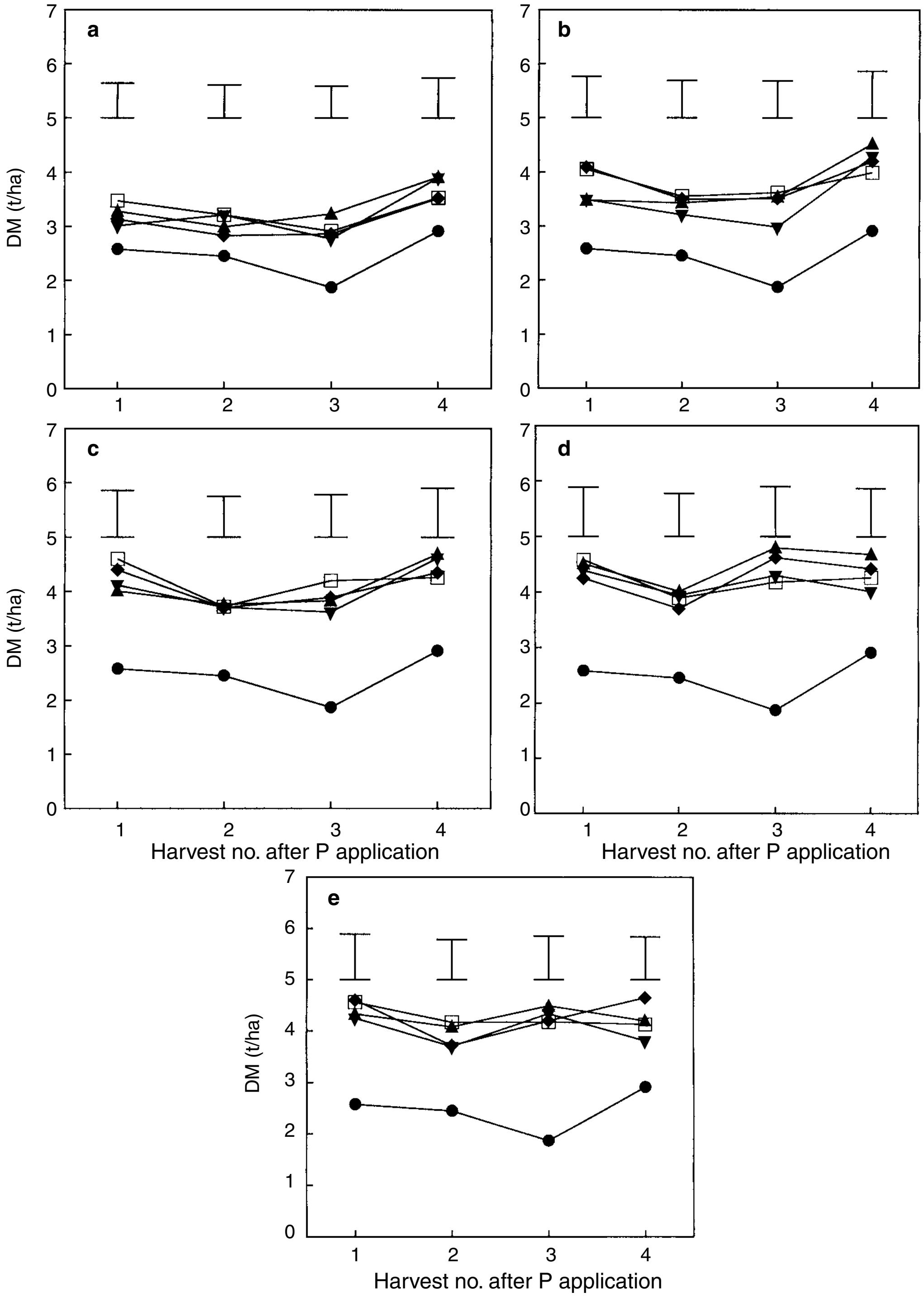


**Figure 1.** Dry matter (DM) yield trends over 4 harvests at: (a) 20; (b) 40; (c) 60; (d) 80; and (e) 100 kg/ha P for triple superphosphate (u), unacidulated rockphosphate (◆), 25% acidulated rockphosphate (▼), 50% acidulated rockphosphate (▲) and control (●). Vertical bars show LSD values at P<0.05.

were similar to DM responses, *i.e.*, all were high and response to PARP25 was slightly lower than response to the other sources. Similar results were obtained in linear response (Table 1).

**Table 1.** Relative yield responses (RYR) and substitution rates (SR) in cumulative DM yield and P uptake for 50% acidulated rockphosphate (PARP50), 25% acidulated rockphosphate (PARP25) and unacidulated rockphosphate (RP) relative to triple superphosphate (TSP). Phosphorus application rates and P uptake are in kg/ha and DM yields are in t/ha.

| P sources | Cumulative DM yield | | | Cumulative P uptake | | |
|---|---|---|---|---|---|---|
| | b | RYR (%) | SR (%) | b | RYR (%) | SR (%) |
| | *Curvilinear response*[1] | | | *Curvilinear response*[2] | | |
| TSP | 0.80 | 100 | 100 | 1.91 | 100 | 100 |
| PARP50 | 0.82 | 103 | 106 | 1.75 | 92 | 85 |
| PARP25 | 0.71 | 89 | 79 | 1.50 | 79 | 62 |
| RP | 0.80 | 100 | 100 | 1.96 | 103 | 106 |
| | *Linear response*[3] | | | *Linear response*[4] | | |
| TSP | 0.14 | 100 | 100 | 0.29 | 100 | 100 |
| PARP50 | 0.14 | 100 | 100 | 0.27 | 93 | 93 |
| PARP25 | 0.11 | 79 | 79 | 0.22 | 76 | 76 |
| RP | 0.14 | 100 | 100 | 0.29 | 100 | 100 |

[1] $Y = 9.80 + b\ \sqrt{\text{P rate}}$.
[2] $Y = 18.58 + b\ \sqrt{\text{P rate}}$.
[3] Y = 9.80 + b (P rate), for 0–40 kg/ha P.
[4] Y = 18.58 + b (P rate), for 0–40 kg/ha P.

The relationship between P uptake by stylo and DM yield was linear up to 30 kg/ha P, above which it was slightly curvilinear (Figure 2c). However, all P sources were represented in all parts of the curve, implying that the internal efficiency of utilisation of P from all 4 sources was similar.

## Discussion

This study has shown that unacidulated Minjingu rockphosphate is equally as effective as triple superphosphate in stimulating growth of stylo on these soils. This supports the findings of Haque *et al.* (1999) where Minjingu rockphosphate and triple superphosphate produced similar responses in *Trifolium quartinianum* on a Vertisol. This rockphosphate is mined in Tanzania, which is not far from Ethiopia, but is not yet commercially available in Ethiopia. When it does become available, whether or not it should be used will depend on its price relative to TSP. Our results indicate that acidulating the rockphosphate for these soils is not justified.

Unfortunately, we did not assess the P levels in the soil after P application. However, Haque and Lupwayi (1998a) recorded growth and P-uptake responses in clover in the Ethiopian highlands up to the seventh crop following P application. This indicates a substantial residual effect on these soils following application of rockphosphates.

The excellent yield responses in stylo of the order of 50% in this study highlight the low phosphorus status of these soils, as reported previously (Kahurananga and Tsehay 1984; Haque *et al.* 1996; Mugwira *et al.* 1997). Nitrogen fixation by these legumes is severely limited by P deficiency because plants without applied P sometimes have no nodules (Haque *et al.* 1996; Mugwira *et al.* 1997). Nodulation and nitrogen fixation were not assessed in this work, but some of the response of plant N (and DM) to applied P is likely to be due to increased nitrogen fixation by the stylo plants, especially since N fertiliser was not applied.

Egyptian rockphosphate has also been found to be highly effective (82–92%) in the Ethiopian highlands, but Togo (54%) and Chilembwe (27%) have been less effective (Haque and Lupwayi 1998a, 1998b; Haque *et al.* 1999). Use of other raw rockphosphates on food crops in other parts of Africa has shown that some rockphosphates are almost as effective as superphosphates in increasing yields (Bationo *et al.* 1990), whereas others are less effective (Bationo *et al.* 1990; Butegwa *et al.* 1996). In incubation and pot experiments with maize in Tanzania, Ikerra *et al.* (1994) found that Minjingu rockphosphate applied alone released so little P that applications of 3 times that of TSP were needed to obtain comparable yields. The contrast with the field results reported here illustrates that rockphosphates are not effective in all soil-crop combinations.

In conclusion, this work has shown that unacidulated Minjingu rockphosphate is highly effective in increasing stylo herbage yields on these soils. Applying this rockphosphate would increase forage production for increased and sustainable crop and livestock productivity.

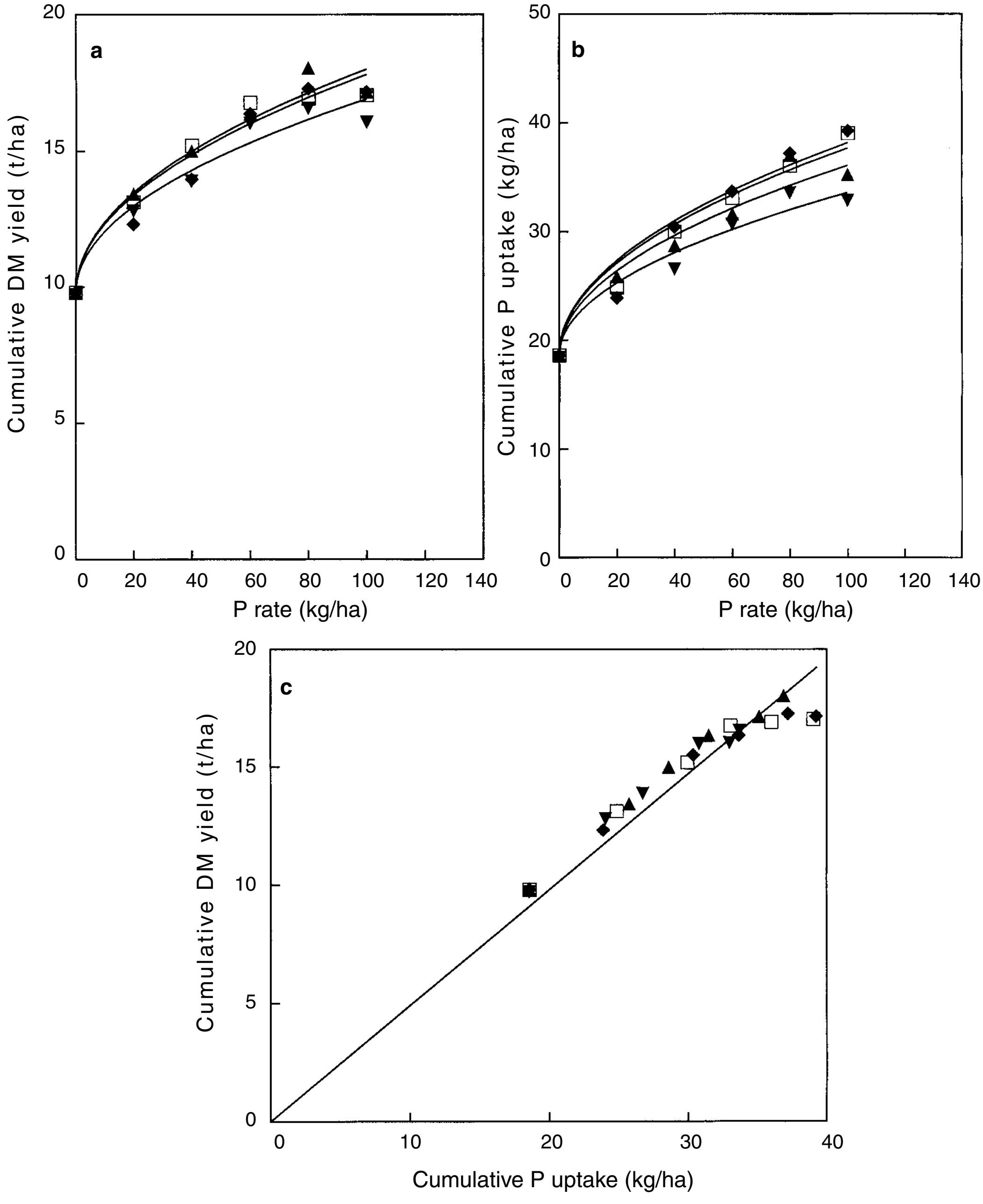


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**Figure 2.** Cumulative response in: (a) stylo dry matter (DM) yield; and (b) P uptake; to triple superphosphate (u), unacidulated rockphosphate (◆), 25% acidulated rockphosphate (▼), 50% acidulated rockphosphate (▲) and control (●). The response equations are given in Table 2. Figure 2c shows the relationship between cumulative DM yield and cumulative P uptake. The relationship can be expressed by the equation: DM yield (t/ha) = 0.49 P uptake (kg/ha) ($r^2$ = 0.89).

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