# Literature review and economic analysis of crop response to phosphate rocks in eastern Africa

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## SUMMARY

DIRECT APPLICATION *of ground phosphate rock to crops grown on acid soil is a simple and low-cost method of substituting refined phosphates, especially if the rock is locally available. The relative agronomic and economic effectiveness of phosphate rocks has been examined using data from the literature and from ILCA trials in the Ethiopian highlands.*

*In general, phosphate rocks gave lower agronomic responses than refined phosphates, but the yields were well above the control. Although the residual effects of phosphate rocks improved yields in 70% of cases, they were rarely large enough to make the use of rock more profitable than that of refined phosphates. The economic effectiveness of phosphate rocks could be improved by using more concentrated rock, which would reduce transportation and other related costs.*

## INTRODUCTION

Increased demand for costly phosphatic fertilizers to improve crop yields necessitated the identification of different phosphate sources as alternatives to refined phosphate (RP) in eastern Africa. One of the first steps was to exploit the large deposits of a primary phosphate (francolite) in Uganda, near the Kenya border. Research on phosphate rock (PR) began in the region in the 1940s (cf EAAJ, 1949; EAAFRO, 1948, 1950, 1951). Some results suggested that direct application of ground phosphate rock could replace refined phosphate on acid soils, especially if the rock is locally available. Haque and Jutzi (1985) came to the same conclusion in Ethiopia.

The literature was reviewed to put available results in a general context and to evaluate them economically. The review sought to answer three questions: What is the performance of phosphate rock compared with other phosphates? What are the conditions under which it raises yields? Is it profitable to use it? The review is supplemented by estimates of responses to rock and other phosphates in trials conducted by ILCA in the Ethiopian highlands.

## STUDIES ON PHOSPHATE ROCKS IN EASTERN AFRICA

### Previous reviews

Duthie and Keen (1953) reviewed crop responses to fertilizers and manures in East Africa (Table 1). Nearly all of the work reported was on cereals, much of it from Kenya, and most of the phosphate studied was Uganda rock phosphate (URP) or sodaphosphate (SOP), a processed form of URP.

**Table 1**. *Sources for the review of phosphate effects on crop production in eastern Africa.*

| Literature source[1] | Area or country | Crop | Phosphate source[2] |
|---|---|---|---|
| *Duthie and Keen (1953)* | | | |
| Jones G H G | Kenya | Mainly wheat | URP, SOP, SP |
| Doughty L R | East Africa | Cereals | SOP, URP, SP |
| Holme R and Sherwood E G P | Kenya | Wheat, maize | URP, SOP, SP |
| Bellis E | Kenya | Wheat, maize | SOP, SHP |
| Kroll U | Kenya | Pyrethrum | URP, SOP, SP |
| Dougall H W | Kenya | Grasses | SP |
| Peat J E | Tanzania | Cotton, millet | SOP, SP |
| Gunn J S | Tanzania | Wheat, tobacco, pyrethrum | SOP, SP |
| Le Mare P H | Tanzania | Groundnuts, maize, sorghum | SP |
| Mills W R | Uganda | Finger millet, maize, cotton | URP, SOP, SP |
| Tidbury G E | Tanzania | Trees, rice, maize, sorghum, sunflower | SP |
| Pereira H C | Kenya | Coffee | URP, SOP, SP |
| Eden T | East Africa | Tea | SP |
| Lock G W | Tanzania | Sisal, grasses | SOP, SP |
| Jones G H G and Robinson P | Kenya | Wheat, maize, sorghum finger millet, | SOP, SP |
| *Jones and Robinson (1965)* | Kenya | Napier grass | NAP, BSG, SP |

| | | | |
|---|---|---|---|
| *Anderson (1965)* | Tanzania | Grass | MRP |
| *Birch (1959)* | Kenya | Clover, oats | URP, SP, KF1, BSG |
| *Gosnell and Weiss (1965)* | Kenya | Napier grass | SOP, NAP, MRP |
| *Haque and Jutzi (1985)* | Ethiopia | Forages | ERP, TRP, SP |

[1] Undated sources are cited in Duthie and Keen (1953).
[2] URP = Uganda rock phosphate; SOP = sodaphosphate; SP = superphosphate; SHP = Seychelles phosphate; NAP = North African phosphate; NRP = neutralised rock phosphate; MRP = Minjingu rock phosphate; BSG = basic slag, KF1 = Kenaf no. 1; ERP = Egyptian rock phosphate; and TRP = Togo rock phosphate.

The vast reserves of phosphate in Uganda were expected to yield fine-grained francolite with an average of 25% phosphoric oxide. Some trials indicated that only about half as much of 'early available' phosphate was released from URP, compared with other commercially worked phosphate rocks, and "it became apparent that Uganda phosphate was not suitable for application by itself to annual crops" (Jones, cited by Duthie and Keen, 1953). Subsequent work was on calcination of URP—which contained about 25% total $P_2O_5$ of which 2–4% was citric acid soluble (c.a.s.)—with crude sodium carbonate to make phosphate more rapidly available.

Doughty (cited by Duthie and Keen, 1953) reported that studies of cereals carried out between 1947 and 1951 on laterised and deeply dissected granite and ancient sediment soils in Tanzania showed URP to be effective. In most experiments, the benefits from its use were apparent only after application for two or three seasons. On lighter-textured upland soils with variable rainfall, triple superphosphate (TSP) was more effective than SOP with 23% total and 19% c.a.s. $P_2O_5$, which in turn was more effective than URP.

Holme and Sherwood (cited by Duthie and Keen, 1953) experimented with URP, SOP and superphosphates (SP) on wheat grown in Kenya during 1948–50. URP at 290 kg $ha^{-1}$ and 580 kg $ha^{-1}$gave negligible responses except in one experiment, and even there it was much less effective than the two other phosphate sources. Only in one area were the effects of double superphosphate (DSP) and SOP equal. In the others, the quantity of the c.a.s. $P_2O_5$ of SOP had to be 20–45% larger in order to give a similar wheat yield per hectare as SP. Similar experiments with maize showed that URP had no appreciable effect in the first year.

Pot experiments on cereals in Kenya showed that although URP had a low early availability, it promised a good response if applied heavily and in a sufficiently fine form (Bellis, cited by Duthie and Keen, 1953).

Sodaphosphate was as effective as an equivalent dressing of SP on tobacco, pyrethrum and wheat planted in Tanzania on granite soils deficient in P; however, high transportation costs made it essential to supply concentrated phosphate (Gunn, cited by Duthie and Keen, 1953).

Mills (cited by Duthie and Keen, 1953) argued that low responses to phosphate in most of the early cereal trials in Uganda were due to the low levels of its application. He reported on experiments comparing the direct effects on maize and the residual effects on cotton of two $P_2O_5$ levels of URP, SP and SOP. At one site with red Latosols, URP and SOP tended to be more beneficial than SP on maize in an abnormally wet year. In trials at another site with similar soil and rainfall conditions, neither URP, SOP or single superphosphate (SSP) increased maize yields significantly, although there was a residual P effect of about an 18% yield increase for all three fertilizers on cotton. At a third site where a yellow Latosol had been fallow under grass for 3 years and then grazed, there was no direct effect on maize and no residual effect on cotton.

Birch (1948) conducted a literature review of soil phosphates. He found that while acidity favoured PR use, fluorine concentration in the rock did not, and that the variable results with PR were, in part, explained by these conflicting tendencies. Large applications of PR, sometimes larger than 2400 kg $ha^{-1}$, may in time approach the effectiveness of SP. He also found that the phosphate sorption capacity of the soil is satisfied only by a large quantity of phosphate rock which changes into a more soluble form only after a long period of time. Therefore, in the short run, RP should be expected to give a greater response. He made no specific mention of PR use with forages.

## Review of material at ILCA

ILCA's library database provided 75 references related to fertilizer and 49 to phosphate use in eastern Africa. From the 124 references, only eight were studies on PR, of which one (Haque and Jutzi, 1985) was done in Ethiopia, while the remaining seven were undertaken in Kenya, Tanzania and Uganda. Further searches provided no references with detailed data. In addition to the literature referred to, many results were inaccessible, such as several reports of the East African Agricultural and Forestry Research Organisation (EAAFRO).

### Ethiopia

In "Some notes on the soil status" (Anon., s.d., a) it was stated that in a sample of 22 Ethiopian soils, of which 19% were 1700 m above sea level, only 8% were not deficient in P. It was concluded that 40% of the soils in the Ethiopian highlands were acid and had a high P fixation capacity.

Haque and Jutzi (1985) reported on the effects of TSP and Egyptian rock phosphate (ERP) on a native Ethiopian clover *(Trifolium steudneri).* The ERP contained 29.4% total $P_2O_5$ of which 12.8% was elemental P. Fertilizers were broadcast on P-deficient Vertisols (1 mg P $kg^{-1}$) with a pH of 6.0. *T. steudneri* was harvested after 96 days.

Egyptian rock phosphate was most effective below 45 kg $P_2O_5$ $ha^{-1}$; at 30 kg $P_2O_5$ $ha^{-1}$ it gave 25% and 18% more DM in 1984 and 1985 respectively than TSP (895 kg DM $ha^{-1}$ and 2485 kg DM $ha^{-1}$) (Table 2). In terms of cumulative effect, TSP was significantly more effective at 45 and 60 kg $P_2O_5$ $ha^{-1}$ , giving 39% and 25% more DM respectively. Overall, the agronomic responses to both sources of P were much higher than the control.

**Table 2.** *Average response (AR) and relative agronomic effectiveness (RAE) of TSP (triple superphosphate) and ERP (Egyptian rock phosphate) on* Trifolium steudneri, *Ethiopia, 1984 and 1985*[a].

| Crop | Source of phosphate | $P_2O_5$ rate (kg $ha^{-1}$) | Direct effect | | Crop | Residual effect | | Cumulative effect | |
|---|---|---|---|---|---|---|---|---|---|
| | | | AR (kg DM $ha^{-1}$) | RAE (%) | | AR (kg DM $ha^{-1}$) | RAE (%) | AR (kg DM $ha^{-1}$) | RAE (%) |
| *T. steudneri* on Vertisols, 1984 | TSP | 15 | 888 | 100.0 | *T. steudneri* on Vertisols, 1985 | 1862 | 100.0 | 2751 | 100.0 |
| | TSP | 30 | 895 | 100.0 | | 2485 | 100.0 | 3379 | 100.0 |
| | TSP | 45 | 1419 | 100.0 | | 7212 | 100.0 | 8631 | 100.0 |
| | TSP | 60 | 2535 | 100.0 | | 3740 | 100.0 | 6275 | 100.0 |
| | ERP | 15 | 1043 | 117.4 | | 2783 | 149.5 | 3826 | 139.1 |
| | ERP | 30 | 1120 | 125.1 | | 2938 | 118.3 | 4058 | 120.1 |
| | ERP | 45 | 1382 | 97.4 | | 3853 | 53.4 | 5235 | 60.7 |
| | ERP | 60 | 1553 | 61.3 | | 3182 | 85.1 | 4736 | 75.5 |

[a] Trials were conducted without additional N.
Sources: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) and Haque and Jutzi (1985).

## Kenya

Gosnell and Weiss (1965) tested the response of Napier grass *(Pennisetum purpureum* Schum.) to different P sources on grey-brown clay soils with a pH of 5.6, which were deficient in N and P (8 mg P kg $^{-1}$ in the top layer). Phosphates were applied at planting and, with the exception of N which was not applied in the first year, they were reapplied annually. An experiment with different rates of TSP showed that 81 kg $P_2O_5$ ha $^{-1}$ applied annually increased the total yield of green matter (GM) over 4 years by about 41% compared to a control yield of 28 t GM $ha^{-1}$.

A second experiment (Table 3) compared the responses to different forms of P and N. The main treatments were TSP, SOP, Minjingu rock phosphate (MRP) with about 30% total and 15% c.a.s. $P_2O_5$, and neutralised rock phosphate (NRP) with 25% total and 11.5% c.a.s. $P_2O_5$. The fertilizers were applied at 45 and 90 kg $P_2O_5$ ha $^{-1}$ in the furrow at planting and not reapplied thereafter. Nitrogen was used as a single dressing of 224 kg $ha^{-1}$ during the second and third years.

**Table 3.** *Average response (AR) and relative agronomic effectiveness (RAE) of rock and refined phosphates in Kenya and Tanzania.*

| Source, crop | Source of phosphate[a] | $P_2O_5$ rate (kg ha$^{-1}$) | Direct effect | | Residual effects 1st year [b] | | Residual effects 2nd year[b] | | Cumulative effect | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | AR[c] (kg ha$^{-1}$) | RAE (%) | AR[c] (kg ha$^{-1}$) | RAE (%) | AR[c] (kg ha$^{-1}$) | RAE (%) | AR[c] (kg ha$^{-1}$) | RAE (%) |
| *Gosnell and Weiss (1965), Kenya* | | | | | | | | | | |
| Napier grass on gray-brown clay soils | TSP | 45 | 13 838 | 100.0 | 6 425 | 100.0 | 2 718 | 100.0 | 22 980 | 100.0 |
| | TSP | 90 | 20 015 | 100.0 | 12 849 | 100.0 | 5 683 | 100.0 | 38 548 | 100.0 |
| | SOP | 45 | 6 425 | 46.4 | 3 954 | 61.5 | 3 212 | 118.2 | 13 591 | 59.1 |
| | SOP | 90 | 15567 | 77.8 | 10 625 | 82.7 | 4 942 | 87.0 | 31135 | 80.8 |
| | NRP | 45 | 9 637 | 69.6 | 5 930 | 92.3 | 2 224 | 81.8 | 17 791 | 77.4 |
| | NRP | 90 | 12 355 | 61.7 | 8 649 | 67.3 | 4 201 | 73.9 | 25 204 | 65.4 |
| | MRP | 45 | 8154 | 58.9 | 3 212 | 50.0 | 2 965 | 109.1 | 14 332 | 62.4 |
| | MRP | 90 | 10 872 | 54.3 | 8 649 | 67.3 | 6 425 | 113.0 | 25 946 | 67.3 |
| *Birch (1959)*, *Kenya* | | | | | | | | | | |
| Clover and oats on weedy, old arable land | TSP | 188 | 35 830 | 100.0 | 7 413 | 100.0 | n.a.[d] | n.a. | n.a. | n.a. |
| | TSP | 282 | 40 030 | 100.0 | 7 413 | 100.0 | n.a. | n.a. | n.a. | n.a. |
| | BSG | 188 | 31 382 | 87.6 | 5 930 | 80.0 | n.a. | n.a. | n.a. | n.a. |
| | BSG | 282 | 34 841 | 87.0 | 9 637 | 130.0 | n.a. | n.a. | n.a. | n.a. |
| | KF1 | 188 | 33 606 | 93.8 | 6 672 | 90.0 | n.a. | n.a. | n.a. | n.a. |
| | KF1 | 282 | 41 019 | 102.5 | 7 413 | 100.0 | n.a. | n.a. | n.a. | n.a. |
| | URP | 75 | 27 244 | 76.0 | 6 336 | 85.5 | n.a. | n.a. | n.a. | n.a. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | URP | 110 | 32 313 | 80.7 | 5 702 | 76.9 | n.a. | n.a. | n.a. | n.a. |
| *Jones and Robinson (1965), Kenya* | | | | | | | | | | |
| Napier grass on red loam soils | DSP | 47 | 2 941 | 100.0 | 741 | 100.0 | n.a. | n.a. | 3 682 | 100.0 |
| | NAP | 47 | 1 261 | 42.9 | 494 | 66.7 | n.a. | n.a. | 1 755 | 47.7 |
| | BSG | 47 | 2 916 | 99.1 | 2 051 | 276.8 | n.a. | n.a. | 4 967 | 134.9 |
| | NAP+ | 47 | 1 681 | 57.2 | 247 | 33.4 | n.a. | n.a. | 1 928 | 52.4 |
| | BSG+ | 47 | 2 546 | 86.6 | 322 | 43.4 | n.a. | n.a. | 2 867 | 77.9 |
| *Anderson (1965),Tanzania* | | | | | | | | | | |
| Grass on Ferrisols and Vertisols | DSP | 53 | 1 019 | 100.0 | 2 401 | 100.0 | 836 | 100.0 | 4 256 | 100.0 |
| | MRP* | 53 | 1 119 | 109.8 | 2 130 | 88.7 | 849 | 101.6 | 4 098 | 96.3 |
| | MRP | 53 | 352 | 34.5 | 2 047 | 85.3 | 692 | 82.8 | 3 091 | 72.6 |

[a] TSP = triple superphosphate; SOP = sodaphosphate; NRP = neutralised rock phosphate; MRP = Minjingu rock phosphate; BSG = basic slag; KF1 = Kenaf No. 1; URP = Uganda rock phosphate; DSP = double superphosphate; NAP = North African phosphate; NAP+ = North African phosphate with ammonium sulphate; BSG+ = basic slag with ammonium sulphate; MRP* = Minjingu rock phosphate with muriafe potash.
[b] First and second residual effect years refer to second and third experiment years.
[c] Gosnell and Weiss (1965) and Birch (1959) reported AR results in green matter and Anderson (1965) and Jones and Robinson (1965) in dry matter (DM).
[d] n.a. = not available.

The effects of fertilizers were marked in the cuts taken during the rains, but there were no significant differences in the dry-season cuts. These affected the annual totals and reduced some results to a non-significant level. Overall, yields were higher at the higher application rate. Though TSP gave the best results for the first and second years, all phosphates gave similar responses in the third year. The P effect lasted 3 years and was still very significant at the fifth cut.

While stimulating yields, phosphate lowered the protein content of the fodder, especially at higher application rates. However, the 3-year mean showed that SOP gave the best protein yields, followed by TSP, MRP and NRP, and all results were well above the protein yield of the control.

Gosnell and Weiss (1965) concluded that the less soluble phosphates (SOP and MRP) gave total GM yields not much lower than TSP, and better protein yields. There was no marked difference between SOP and MRP at equivalent levels of $P_2O_5$, and phosphate did not have to be reapplied for at least the first 2 years after the first application since residual effects were important.

Birch (1959) reported that high levels of $P_2O_5$ (212 kg $ha^{-1}$) doubled ryegrass yields on very weedy, old arable land (pH 5.3). A second experiment compared the effects of TSP and basic slag (BSG), which had about 18.1% total and 14.5% c.a.s. $P_2O_5$, on *Trifolium tembense* grown on a soil with a pH of 5.0. There was a log-linear effect of TSP, which was greater than that of the slag. The effect of BSG declined at a higher rate of application. The response of the legume to phosphate was in general significantly higher than the control.

A third experiment involved subterranean clover and Lampton oats on a soil of pH 5.1; the oats were sown in the second year of the trial after the clover had been harvested (Table 3). Kenaf no. 1 (KF1), TSP and BSG at 0, 188 and 282 kg $P_2O_5$ $ha^{-1}$, and URP at 75 and 110 $P_2O_5$ kg $ha^{-1}$, were compared. Two bare fallowed plots, one with the higher rate of TSP and one without phosphate, were also compared. Three cuts were taken. Although URP did not stimulate clover yields much, the protein content of the URP-fertilized clover was only slightly lower than that of the TSP fertilized clover.

Uganda phosphate gave significantly lower oat yields than did soluble chemical phosphates. The fallowed plot with TSP (282 kg $P_2O_5$ $ha^{-1}$) outyielded all other oats plots. The protein content of oats was less with TSP than with the other phosphates.

Jones and Robinson (1965) evaluated three types of phosphate applied to Napier grass *(Pennisetum purpureum)* on red loam soils (Table 3). Napier was planted during the short rains of 1953, after a harvest of a maize silage crop in the previous season. DSP, North African rock phosphate (NAP) with 29% c.a.s. $P_2O_5$ and BSG were compared, the last two with and without ammonium sulphate. DSP and BSG significantly raised yields but not significantly more than ammonium sulphate alone which gave a DM response of 1730 kg $ha^{-1}$. The NAP plots showed the least response, both with and without ammonium sulphate, and a similar lower residual effect. The authors concluded that consistent yield increases were obtainable with DSP and BSG at 47 kg $P_2O^5$ $ha^{-1}$.

### Tanzania

Anderson (1965) compared the effects of MRP and DSP on grass at three sites representing major soil types in Tanzania. Three treatments were applied to each of the sites in 1960: DSP, MRP and MRP with muriate of potash. In 1961, the plots were trimmed and all treatments reapplied. The means of all site yields (Table 3) for 1961–63 showed no marked differences between treatments, but all treatments were significantly better than the control. Response to MRP was lower than that to DSP. The low direct response suggests that MRP was inferior to DSP on annual crops, but not on permanent pastures because of the residual effects.

On poor red soils, 125 kg DSP $ha^{-1}$ or 375 kg MRP $ha^{-1}$—an equivalent of 53 kg $P_2O_5$ $ha^{-1}$—could increase the stocking rate by 50% for at least 2 years. Economic analysis at one site showed a return of 45 kg DM per shilling invested in DSP, in the presence of adequate N. At another site, the return was 13 kg DM per shilling invested. Overall, MRP gave only about 75% of the agronomic response of DSP, but should be cheaper to use because it is locally obtainable.

The Mlingano and Naliendele Agricultural Research Institutes of Tanzania undertook 6-year comparative fertilizer trials (Anon., s.d., b and c). PR, TSP and a TSP/PR mixture were applied periodically to cereals on a rhodic Ferralsol and luvic Arenosol with respectively 6.7 and 5.0 pH and 4.7 and 5.1 mg P $kg^{-1}$. The trials were completed in 1986 after all plots had received a total of 180 kg $P_2O_5$ ha t.

Phosphate rock applied at the rate of 30 kg $P_2O_5$ $ha^{-1}$ every season over the 6 years gave a total maize response much higher than did TSP at the same rate. However, when fertilizers were applied at 60 kg $P_2O_5$ $ha^{-1}$ every second season or 90 kg $P_2O_5$ $ha^{-1}$ every third season, the maize response to PR was significantly lower than that to TSP. With only an initial application of 180 kg $P_2O_5$ $ha^{-1}$, response to PR was 17% more than the total maize response to TSP over the 6 years (3770 kg $ha^{-1}$). Fertilizer mixture was more efficient when PR and TSP were used at the rates of 60 and 30 kg $P_2O_5$ $ha^{-1}$ rather than the reverse. Response to PR was, in most cases, relatively lower in the first year.

Similar trials showed that the response of sorghum to PR was at least 30% lower than that to TSP at all rates considered. The trials with the TSP/PR mixture gave almost the same results as those with maize which at the best rate yielded an average of 800 kg $ha^{-1}$ $year^{-1}$ over the control.

For both sorghum and maize, the return per shilling invested in fertilizer was higher for PR because the cost of TSP was almost three times more than that of PR, assuming that the fertilizer prices are farm gate prices and that all other costs are equal for both phosphate sources. However, price and yield variations over the 6 years might affect this result.

# RELATIVE EFFECTIVENESS OF PHOSPHATE ROCKS

## Relative agronomic effectiveness (RAE)

Tables 2 and 4 show average response (AR) and relative agronomic effectiveness (RAE), calculated from the Ethiopian data. Average response is the mean change in yield over the control as a result of fertilization. Relative agronomic effectiveness is the percentage representation of AR to phosphate fertilizers in the AR to RP at the same rate. The RAE of PR is for example computed as:

$RAE_{pr} = (AR_{pr}/AR_{rp}) \times 100$

where: pr = phosphate rock, and rp = refined phosphate (SPs).

Accordingly, the RAE of SP is at any given rate equal to 100. RAE is estimated at equivalent rates of fertilizer application.

### Direct effects

Table 2 shows that in 1984, the RAE of ERP on *Trifolium steudneri* was 117 and 125% at 15 and 30 kg $P_2O_5$ $ha^{-1}$ respectively, but was only 61 % at 60 kg $P_2O_5$ ha I . Much better RAEs were obtained in 1985 at the rates of 15 and 60 kg $P_2O_5$ $ha^{-1}$.

Results with *T. quartinianum* show that the RAEs of ERP are below 70% in all cases (Table 4). The performance of Togo rock phosphate (TRP), which has 36.7% total $P_2O_5$ and 16%

elemental P, was even less. Lucerne response to ERP and TRP gave RAEs less than 85%, although the RAEs of ERP were usually higher than those of TRP. Only in one case did ERP (at 160 kg $P_2O_5$ ha$^{-1}$) give a better RAE (122%).

**Table 4.** *Average response (AR) and relative agronomic effectiveness (RAE) of rock and refined phosphates, Ethiopia, 1985.*[a]

| Crop | Source of phosphate[b] | $P_2O_5$ rate (kg ha$^{-1}$) | Direct effect | |
|---|---|---|---|---|
| | | | AR (kg DM ha$^{-1}$) | RAE (%) |
| *T. quartinianum* on Vertisol, 1985 | TSP | 20 | 1 093 | 100.0 |
| | TSP | 40 | 2 060 | 100.0 |
| | TSP | 80 | 3 423 | 100.0 |
| | TSP | 160 | 3 178 | 100.0 |
| | ERP | 20 | 259 | 23.7 |
| | ERP | 40 | 679 | 32.9 |
| | ERP | 80 | 1 911 | 55.8 |
| | ERP | 160 | 2 176 | 68.5 |
| | TRP | 20 | 87 | 8.0 |
| | TRP | 40 | 604 | 29.3 |
| | TRP | 80 | 805 | 23.5 |
| | TRP | 160 | 1 516 | 47.7 |
| Lucerne on upland soil, 1985 | TSP | 20 | 492 | 100.0 |
| | TSP | 40 | 849 | 100.0 |
| | TSP | 80 | 1 062 | 100.0 |
| | TSP | 160 | 1 090 | 100.0 |
| | ERP | 20 | 326 | 66.2 |
| | ERP | 40 | 544 | 64.1 |
| | ERP | 80 | 861 | 81.1 |
| | ERP | 160 | 1 326 | 121.6 |
| | TRP | 20 | 274 | 55.7 |
| | TRP | 40 | 452 | 53.3 |
| | TRP | 80 | 683 | 64.3 |
| | TRP | 160 | 659 | 60.5 |
| *T. quartinianum* on Vertisol, 1985 | TSP | 60 | 7 760 | 100.0 |
| | TSP/ERP | 45/15[c] | 2 704 | 34.8 |
| | TSP/ERP | 30/30 | 3 690 | 47.6 |

| | | | | |
|---|---|---|---|---|
| | TSP/ERP | 15/45 | 3 305 | 42.6 |
| | ERP | 60 | 2 810 | 36.2 |
| *T. quartinianum* on Vertisol, 1985 | TSP | 60 | 3 245 | 100.0 |
| | TSP/TRP | 45/15[d] | 3 518 | 108.4 |
| | TSP/TRP | 30/30 | 2 292 | 70.6 |
| | TSP/TRP | 15/45 | 2199 | 67.8 |
| | TRP | 60 | 1713 | 52.8 |
| *Desmodium sanduicense*on upland soil, 1985 | TSP | 50 | 1299 | 100.0 |
| | TSP/ERP | 37/12[c] | 1252 | 96.4 |
| | TSP/EPR | 25/25 | 1007 | 77.5 |
| | TSP/ERP | 12/37 | 1263 | 97.2 |
| | ERP | 50 | 1125 | 86.6 |

[a] Trials were conducted without additional N. Residual values were not available.
[b] TSP = triple superphosphate; ERP = Egyptian rock phosphate; TRP = Togo rock phosphate.
[c] Rates of $P_2O_5$ from TSP and ERP respectively.
[d] Rates of $P_2O_5$ from TSP and TRP respectively.
Sources: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) and Haque and Jutzi (1985).

Mixtures of TSP and ERP were applied to *Desmodium sanduicense* and *T. quartinianum* (Table 4). Comparable TSP/TRP mixtures were also used on *T. quartinianum.* On desmodium, there was no significant difference between TSP/ERP applications of 37.5/12.5 kg $P_2O_5$ $ha^{-1}$ and 12.5/37.5 kg $P_2O_5$ $ha^{-1}$. On trifolium, the highest fraction of TSP in the TSP/TRP mixtures and an equal proportion of TSP/ ERP gave better results. The higher the proportion of TSP in the TSP/TRP mixture, the better were the RAEs.

Table 3 shows analyses from the literature review in Kenya and Tanzania. There is some difficulty in comparing results because of the use of different crops and materials. Nonetheless, it appears that PRs were generally inferior to RPs, while their yields were often superior to controls.

### Residual effects

Because phosphate rocks release P more slowly than refined phosphates, the profitability of using rock sources should be higher if residual effects are included. In Tables 2 and 3, residual effects are examined by comparing the cumulative RAE to the direct RAE – if the cumulative RAE is greater, then including residual effects improves the value of phosphate rock.

Using TSP as a reference, only four residual values are available for ERP in Table 2; two are greater than the direct RAE, therefore rock values are not improved by including residual effects. In Table 3, nine out of 12 values are greater than the direct effects, so it is possible to conclude that residuals improve the agronomic efficiency of phosphate rocks. This is also supported by most results of the 6-year trials with cereals in Tanzania.

## Effects of phosphate rocks on protein yield

In general, phosphates did not improve the protein content of fodder except in clover response to ERP and URP. Although phosphate rocks were not as quick stimulants of response as refined phosphates, they gave better or comparable protein content. It is possible to conclude that adjusting DM results for protein content might favour phosphate rock use, and that both rock and refined phosphates would raise the yield of protein per hectare.

## Effects of phosphate rocks on cereals

Phosphate rock was tried on cereals. Apart from very few applications on maize, rock gave lower responses than did refined phosphates, although detailed trial results were not always available. In the 6-year comparative trials in Tanzania, PR was agronomically less efficient on sorghum than TSP. The tendency for rock to be inferior on cereals suggests that PRs would be more effective in long-term fodder production, because of residual effects.

## Relative economic effectiveness (REE) of phosphate rocks

The economics of phosphate rocks depend mainly on phosphate prices, on the RAE value, and on the concentration of $P_2O_5$ in each source. Because of rock's lower concentration, transportation costs will favour refined phosphates. The relative economic effectiveness (REE) is:

$$REE = RAE \times (P_{rp}/P_{pr})$$

where:

$P_{rp}$ = price per kg $P_2O_5$ of refined phosphate, and

$P_{pr}$ = price per kg $P_2O_5$ of phosphate rock (Haque and Godfrey-Sam-Aggrey, 1980).

The assumptions used in calculating the prices of $P_2O_5$ delivered to Addis Ababa are:

| | *ERP* | *TRP* | *TSP* |
|---|---|---|---|
| Average price (US$ $t^{-1}$ product) | 45 | 45 | 155 |

| | | | |
|---|---|---|---|
| $P_2O_5$ content (%) | 29.4 | 36.7 | 46.0 |
| Transportation costs to Addis Ababa | = US$ 100 $t^{-1}$ product | | |
| Cost of $P_2O_5$ at Addis Ababa (US$ $t^{-1}$) | 493 | 395 | 554 |

Because TSP sources of $P_2O_5$ are 12–40% more expensive than PR, rock can be that much less agronomically efficient than TSP and still be competitive. If the prices of rock and refined phosphates per kg of nutrient were equal, the REE would be equal to the RAE for any comparison. If rock phosphate has an REE greater than 100, it is more profitable than refined phosphate at the specified rate. This approach assumes that application, handling and other costs are equal for all phosphate sources.

Table 5 shows that phosphate rocks are economically less efficient on *T. quartinianum* and lucerne, except at one rate on lucerne. ERP was generally more efficient at 30 kg $P_2O_5$ $ha^{-1}$ or less on *T.steudneri.* On desmodium only a 1:1 mixture of $P_2O_5$ from TSP and ERP and ERP alone were less effective. This is partly due to the lower agronomic efficiency of phosphate rock compared to that of refined phosphate, and partly to the higher price of $P_2O_5$ $kg^{-1}$ because of the higher transportation costs for rock. With *T. steudneri,* inclusion of residual effects improved the results only at the rates of 15 and 60 kg $P_2O_5$ $ha^{-1}$.

**Table 5.** *Relative economic effectiveness (REE) of rock and refined phosphates, Ethiopia, 1984 and 1985*[a]*.*

| Crop | Source of phosphate[b] | $P_2O_5$ rate (kg $ha^{-1}$) | REE | |
|---|---|---|---|---|
| | | | Direct effect (%) | Cumulative effect (%) |
| *T. steudneri* on Vertisols, 1984 | TSP | Any | 112.2 | 112.2 |
| | ERP | 15 | 131.7 | 156.1 |
| | ERP | 30 | 140.5 | 134.8 |
| | ERP | 45 | 109.3 | 68.1 |
| | ERP | 60 | 68.8 | 84.7 |
| *T. quartinianum* on Vertisols, 1985 | TSP | Any | 112.2 | n.a.[c] |
| | ERP | 20 | 26.6 | n. a. |
| | ERP | 40 | 37.0 | n. a. |
| | ERP | 80 | 62.7 | n.a. |
| | ERP | 160 | 76.9 | n.a. |

| | | | | |
|---|---|---|---|---|
| | TSP | Any | 140.3 | n.a. |
| | TRP | 20 | 11.2 | n.a. |
| | TRP | 40 | 41.1 | n.a. |
| | TRP | 80 | 33.0 | n.a. |
| | TRP | 160 | 66.9 | n.a. |
| Lucerne on upland soil, 1985 | TSP | Any | 112.2 | n.a. |
| | ERP | 20 | 74.3 | n.a. |
| | ERP | 40 | 71.9 | n.a. |
| | ERP | 80 | 91.0 | n.a. |
| | ERP | 160 | 136.5 | n.a. |
| | TSP | Any | 140.3 | n.a. |
| | TRP | 20 | 78.1 | n.a. |
| | TRP | 40 | 74.7 | n.a. |
| | TRP | 80 | 90.2 | n.a. |
| | TRP | 160 | 84.8 | n.a. |
| *T. quartinianum* on Vertisols, 1985 | TSP | Any | 112.2 | n.a. |
| | TSP/ERP | 45/15 | 39.1 | n.a. |
| | TSP/ERP | 30/30 | 53.4 | n.a. |
| | TSP/ERP | 15/45 | 47.8 | n.a. |
| | ERP | 60 | 40.6 | n.a. |
| *T. quartinianum* on Vertisols, 1985 | TSP | Any | 140.3 | n.a. |
| | TSP/TRP | 45/15 | 152.1 | n.a. |
| | TSP/TRP | 30/30 | 99.1 | n.a. |

| | | | | |
|---|---|---|---|---|
| | TSP/TRP | 15/45 | 95.1 | n.a. |
| | TRP | 60 | 74.0 | n.a. |
| *Desmodium sanduicense* on upland soil, 1985 | TSP | Any | 112.2 | n.a. |
| | TSP/BRP | 37/12 | 108.2 | n.a. |
| | TSP/BPR | 25/25 | 87.0 | n. a. |
| | TSP/ERP | 12137 | 109.1 | n. a. |
| | ERP | 50 | 97.2 | n.a. |

[a] Trials were conducted without additional N. Fertilizer prices are as shown in the text. $P_2O_5$ content is 46 % for TSP, 29.4 % for ERP and 36.7 % for TRP. Because the RAE of TSP equals 100, the REE of TSP gives the percentage difference in price between TSP and TRP.
[b] TSP = triple superphosphate; ERP = Egyptian rack phosphate; TRP = Togo rock phosphate.
[c] n.a. = not available.
Sources: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) and Haque and Jutzi (1985).

Table 6 shows the REEs of various rock and refined phosphates on forage crops in Kenya and Tanzania. URP, MRP, NRP and NAP seem to be clearly less efficient, except in one instance on grass in Tanzania where MRP was used with muriate of potash (Anderson, 1965). Inclusion of residual effects did not change the results. Sensitivity analysis of the REEs to changes in fertilizer cost showed that a decline as large as 50% in PR price or in the transportation costs of product did not affect most of the results.

**Table 6.** *Relative economic effectiveness (REE)[a] of rock and refined phosphates, Kenya and Tanzania.*

| Source, crop | Source of phosphate [b] | $P_2O_5$ rate (kg ha$^{-1}$) | REE | |
|---|---|---|---|---|
| | | | Direct effect (%) | Cumulative effect (%) |
| *Gosnell and Weiss (1965), Kenya* | | | | |
| Napier grass on gray-brown clay soils | TSP | Any | n.a.[c] | n. a. |
| | SOP | 45 | 40.8 | 52.0 |
| | SOP | 90 | 68.4 | 71.0 |
| | NRP | 45 | 66.6 | 74.0 |

| | | | | |
|---|---|---|---|---|
| | NRP | 90 | 59.0 | 62.5 |
| | MRP | 45 | 67.6 | 71.5 |
| | MRP | 90 | 62.3 | 77.2 |
| *Birch (1959), Kenya* | | | | |
| Clover on weedy, old arable land | TSP | Any | n.a. | n.a. |
| | BSG | 188 | 60.6 | n.a. |
| | BSG | 282 | 60.2 | n.a. |
| | URP | 75 | 68.3 | n.a. |
| | URP | 110 | 72.5 | n.a. |
| *Anderson (1965), Tanzania* | | | | |
| Grass on Ferrisols and Vertisols | DSP | 53 | n.a. | n.a. |
| | MRP* | 53 | 138.0 | 121.0 |
| | MRP | 53 | 43.4 | 91.2 |
| *Jones and Robinson (1965), Kenya* | | | | |
| Napier grass on red loam soils | DSP | 47 | n.a. | n.a. |
| | NAP | 47 | 52.1 | 57.9 |
| | BSG | 47 | 75.1 | 102.2 |
| | NAP+ | 47 | 69.4 | 63.6 |
| | BSG+ | 47 | 65.6 | 59.0 |

[a] Calculated from the literature.
[b] TSP = triple superphosphate; SOP = sodaphosphate; NRP = neutralised rock phosphate; MRP = Minjingu rock phosphate; BSG = basic slag; URP = Uganda rock phosphate; DSP = double superphosphate; MRP* = Minjingu rock phosphate with muriate potash; NAP = North African phosphate; NAP+ = North African phosphate with ammonium sulphate; BSG+ = basic slag with ammonium sulphate.
[c] n.a. = not available.

## Possible reasons for the poor agronomic performance of phosphate rocks

literature suggests that PRs gave poorer agronomic performances because of low solubility and P release. As few trials were undertaken with more than two PR rates, it is also possible that fertilizers were used below or above the appropriate rates, thereby affecting the yield. In most cases, residual effects were not tested for longer than 2 years. Because the trials were done under different conditions—using different plants, sites, methods and times of application—it is difficult to estimate the effects of other factors. For example, Anderson (1965) reported that when the same trial was done in three sites, the responses to MRP differed markedly although the comparison with refined phosphate did not differ as much.

# CONCLUSIONS

All studies confirmed a phosphate response. The response was probably greater on acidic soils, and was found in cereals, forages and tree crops. Overall, phosphate rocks gave poorer responses than refined phosphates. Only *T*. *steudneri* in Ethiopia and pyrethrum (genus *Chrysanthemum)* in Kenya gave better agronomic responses to PR than to RP in the year of application.

It has generally been suggested that residual effects will be greater for phosphate rocks. Few experiments measured such effects: those outside Ethiopia confirmed that residual effects favoured rock application, although the residuals were never large enough to effect any significant changes in the economic efficiency of rock relative to that of refined phosphate.

The poorer agronomic response to phosphate rocks makes the economics of using them marginal. There were some clear instances where it would be profitable to use phosphate rocks, but identification of such cases depends on the type of crop, rock, soil and other factors. Whatever the physical responses to phosphate rock, it will still be necessary to use more concentrated rocks in order to reduce the burden of transportation and other related costs, especially if the rock is not locally available. In addition, if rock is more difficult to apply than refined phosphate, then application costs should be considered in any further economic analysis.

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