THE USE OF ORGANIC AND GEOLOGICAL MATERIALS FOR SOIL FERTILITY MAINTENANCE IN THE SOUTHERN HIGHLANDS OF TANZANIA

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ABSTRACT

Over 40% of smallholder farmers use organic materials for soil improvement but currently only very broad, imprecise advice is available to guide them. Large yield responses have been observed when organic manures have been applied, and the application of organic manure has increased the response to inorganic fertilizer. Placement of organic manure below the seed gave much larger yield increases than broadcasting or incorporation the manure into the soil. The equivalence between organic and inorganic fertilizers varies with season and site, but a conservative approximation is that one tonne of organic manure gives yield increases equivalent to 15-20 kg inorganic nitrogen in maize, and equivalent to 5-10 kg inorganic nitrogen in Phaseolus beans, for mid-altitude areas. It is estimated that the use of up to 20 t ha^{-1} organic manure is economically justified in maize production and up to 10 t ha^{-1} in beans, provided it can be obtained and applied at a cost between 2000-5000 TSh a tonne, for the mid to high altitude areas.

Locally available rock phosphates can profitably be used as a source of phosphorus in crop production instead of triple superphosphate (TSP), especially on acid soils. Rock phosphate at 40 kg P ha^{-1}, (equivalent to 250 kg ha^{-1} (five bags) of Panda Rock Phosphate) was found to be the best rate for increasing the yields of maize, particularly when the phosphate was applied under the seed or in the row. Re-application every three or four years is needed to sustain yields. Rock phosphate needs to be sold at about 750 TSh per 50 kg bag if it is to compare with the price of TSP.

INTRODUCTION

The Southern Highlands of Tanzania occupies approximately one-fifth of Tanzanian's total land area, and is known as the 'grain basket' or 'granary' of the nation, mainly because of its well distributed and reliable rainfall and fertile soils. Kamasho *et al.* (1991) categorized the Southern Highland soils into rhodic, humic, xanthic and orthic Ferralsols, eutric Fluviosols and Arenosols, mainly low activity clays. The soils are highly variable in their soil nutrient content and response to fertilizer application. In all cases the soils are generally deficient in nitrogen, phosphorus and several micro-nutrients (such as copper, zinc and boron) (Kamasho and Singh, 1980). Inherently poor parent materials, and losses due to erosion and crop removal at harvest, have been the major causes of the poor nutrient content of these soils (Chowdhury *et al.*, 1983). The use of fertilizers has been the main method of improving the soils' fertility status and productivity. Fertilization has in general been thought of in terms of inorganic (chemical) fertilizer use. The use of alternative sources of soil fertility maintenance has received little attention, and there are no up-to-date recommendations for farmers on their use. Stocking (1988) warned against the view that nutrients applied 'out of the bag' can serve as a panacea for all soil fertility problems, as chemical fertilization of inherently fertile soils may lead to problems of acidification, nutrient imbalance and trace element deficiency. Unreliable and late supplies of chemical fertilizers, and their high costs, have constrained their use by smallholder farmers.

Well over 60% of the most imports fertilizers imported into Tanzania are consumed in the Southern Highlands. Most imports are of urea, sulphate of ammonia, calcium ammonium nitrate and triple superphosphate, with small amounts of NPK compound fertilizer also being imported (ASSP, 1992). However, there is evidence to indicate that many soils in Tanzania are deficient in other plant nutrients, such as copper, boron or zinc, which could be corrected using alternative (for example, organic and geological) fertilizer sources. Organic fertilizer, are known to contain an ample supply of nitrogen (0.1-0.2%) and potassium, and smaller amounts of phosphorus. Organic fertilizers can contribute small amounts of a range of nutrients and so correct multiple soil deficiencies (Stephens, 1969). They are important in improving soil structure, tilth, porosity, water holding capacity and infiltration rate. Chemically, organic fertilizers can improve the cation exchange and buffering capacities of soils, and the chelation of metallic ions. They can enhance microbial activity, and help conserve soil and water, hence they increase crop yields. Yet organic manures are little used in the production of crops in Tanzania.

This paper addresses options other than the use of imported chemical fertilizers for maintaining soil fertility. The paper has the following three objectives:

1. To review the current use of organic fertilizers and geological materials by smallholder farmers;

2. To review research on alternative methods of soil fertility maintenance and improved use of organic fertilizers;

3. To outline future activities aimed at improved use of alternative fertilizer sources.

CURRENT USE OF ALTERNATIVE FERTILIZER SOURCES BY SMALLHOLDERS IN THE SOUTHERN HIGHLANDS

Estimates indicate that Tanzania is able to produce approximately 11 million t of manure from 19 million head of livestock. This is equivalent to 77,000 t of nitrogen a year, which is more than three times the amount of nitrogen (22,041 t) used in the country in 1980 (Gabel and Heiband, 1983; Kyomo and Chagula, 1983). The Southern Highlands alone, with 2.6 million head of cattle (Akarro, 1992), produce 13 million t of manure, which could yield about 10,500 t of nitrogen a year. This could meet the nitrogen requirements of the zone's major food crops. However, only a small proportion of the manure is used for agricultural production. Much is currently unavailable because cattle are usually allowed free range, and is being used for other purposes such as fuel. Nevertheless, surveys by the ASSP Food Security project in 1988 revealed that many farmers in the Southern Highlands do use organic fertilizer (manure and compost) alongside inorganic fertilizers in the production of major food and cash crops (Table 1). Mbeya, Mbozi, Njombe and Mbinga Districts had the highest proportion of farmers using farmyard manure (FYM), probably because of the relatively large numbers of livestock kept in those districts. Mbinga District had the highest proportion of farmers using compost.

Table 1. Proportion of farmers (%) using different types of fertilizer in the Southern Highlands (CAN, calcium ammonium nitrate; TSP, triple superphosphate)

District	CAN	Compost	Unspec.	NPK	SA	Manure	TSP	Urea
Mbinga	5	18	11	0	17	31	0	16
Iringa	29	2	2	3	0	29	18	13
Njombe	12	3	0	7	0	35	16	12
Mbozi	23	9	0	0	0	44	8	10
Songea	2	2	0	0	56	8	0	24
Mbeya	7	9	10	0	0	47	12	11
Mean	13	7	4	2	12	33	9	14

Source: ASSP, 1988.

The *ngoro* system of land preparation practised by the Wamatengo of Mbinga utilizes a substantial amount of grass compost. Maize and coffee receive nearly all the organic fertilizer used by farmers in the Southern Highlands, mainly supplied as basal dressings. Manure is either collected and applied daily or heaped in piles and spread in the field when dry (ASSP, 1988). Bulkiness and limited availability, and a lack of know-how among farmers about preparing and using compost and manure are the main limitations to their use of reported by farmers (ASSP, 1988). In addition to this, farmers who have been using the materials have done so without proper guidelines or recommendations.

Currently no data are available on the use of rock phosphates in the production of crops in Tanzania. The Minjingu Phosphate Co Ltd. has recently started to issue small quantities of ground phosphate rock for direct use as a phosphate fertilizer. However, the technology has yet to be adopted by smallholders.

RESEARCH REVIEW

Organic manures

There has been a considerable amount of research worldwide on the response of crops to organic manure application, mainly concerned with the nutrients supplied and the best time rate and methods of application (Singh, 1988). In Tanzania, research on organic manures dates as far back as the 1950s, and has been conducted mainly at Ukiriguru, Kongwa, Urambo, Nachingwea and Mlingano (Le Mare, 1953; Evans and Mitchell, 1962; Peat and Brown, 1962; Scaife, 1968). Significant responses have been reported in cotton, maize, bulrush millet, groundnuts and sisal. For example, 25 t ha^{-1} of FYM gave the best highest yields of maize and groundnuts in the old Groundnut Scheme areas (Kongwa, Nachingwea and Urambo). By supplementing FYM with artificial fertilizers, Le Mare (1953) obtained a response from artificial fertilizer better than or equal to that with FYM alone in the year of application, and with residual effects from the FYM for up to eight years. In an experiment conducted by Gunn (1953) to study the effect of FYM on wheat and tobacco in the Southern Highlands of Tanzania, 12.5 t ha^{-1} of FYM gave the maximum yields.

With the advent of 'cheap' chemical fertilizers the interest in organic fertilizers declined. After 1970, soil fertility work in Tanzania was directed mainly towards inorganic fertilizer studies. However, the increasing prices of chemical fertilizer, and increasing awareness of the inability of smallholders to obtain chemical fertilizer in sufficient quantities, led to experiments with organic manures, either alone or supplemented by chemical fertilizers, at Uyole Agricultural Centre (UAC) and later on in other parts of the Southern Highlands during the 1970s and 1980s. The main objectives of these experiments were:

1. To study the effect of organic fertilizers, and of the rate and methods of application, on soil properties and crop yields;

2. To study the residual effects of these materials;

3. To evaluate the possibility of substituting organic fertilizers for mineral fertilizers, either wholly or partially.

In these experiments, farmyard manure was collected from cattle sheds, whilst compost manure (CM) was prepared using the pit method described by Ngeze *et al.* (1983). Laboratory analysis of the manures was carried out prior to experimentation (Table 2). Maize and beans were the test crops.

Maize. Experiments to investigate the effect of farmyard manure alone on the yield of maize were conducted at UAC in the mid 1970s. The rates used varied from 0 to 40 t ha^{-1} per hectare. Farmyard manure was applied below the seed in the planting hole at seeding. The results showed a steady increase in the yield of maize as the amount of manure was increased from 5 to 40 t ha^{-1} (Table 3).

However, significant yield differences over the control were obtained only at the highest rate of application (40 t ha^{-1}). The results suggest that more than 30 t ha^{-1} of farmyard manure are likely to be needed for maximum maize production (Temu, 1992).

In later trials conducted in 1980/81 at two sites (Uyole and Mbimba), farmyard manure (FYM) was supplemented with low rates of nitrogenous fertilizer. The resulting maize yields are shown in Table 4. When 40 kg N ha^{-1} plus 15 kg P ha^{-1} were applied, the maize yield was 4 t ha^{-1}. Yield increased to 7 t ha^{-1} with the additional application of 20 t ha^{-1} FYM, indicating the need for farmers to apply as much FYM as is available, in addition to inorganic fertilizers (Temu, 1992).

In a more recent experiment (1984-88) two different types of organic manures were compared with different applications of inorganic nitrogen (Table 5). In the absence of inorganic fertilizer, application of organic manures resulted in a linear increase in the yield of maize, from 2.7 to 4.2 t ha^{-1} with FYM, and from 2.7 to 4.7 t ha^{-1} with compost. The data suggest that compost may be superior to FYM in increasing maize yields, perhaps because of the higher phosphorus content of compost (Table 2). Addition of inorganic nitrogen increased yields still further, irrespective of the source of organic manure applied. Applying 120 kg N ha^{-1} with either 10 or 20 t ha^{-1} of compost resulted in the highest maize yields.

Table 2. Nutrient composition of organic manure used in experiments on maize and beans

Crop	Manure	Org. C. (%)	P (%)	N (%)
Maize	FYM	24.3	0.23	0.58
	CM	35.0	0.65	0.42
Beans	FYM	29.0	0.33	0.52
	CM	37.0	0.61	0.37

Table 3. Effects of different rates of farmyard manure on maize yields in experiments carried out at UAC in the 1970s

FYM (t ha^{-1})	Yield (t ha^{-1})	Yield increase over control (%)
0	2.2	100
5	2.5	117
10	2.0	121
20	3.7	169
40	4.9	224

Table 4. Response of maize to farmyard manure (FYM) supplemented with mineral fertilizers (means of trials carried out at Uyole and Mbimba, 1980/81)

Treatment	Yield (t ha^{-1})	Yield increase over (control)
No FYM, no fertilizer	3.04	0
5 t ha^{-1} FYM	4.49	148
20 t ha^{-1} FYM	4.49	148
20 t ha^{-1} FYM in year 1 only	5.12	168
20 t ha^{-1} FYM, in year 1 + 40 kg N ha^{-1} annually	6.82	244
20 t ha^{-1} FYM in year 1, + 40 kg N ha^{-1} and 15 kg P ha^{-1} annually	7.01	231
40 kg N ha^{-1} and 15 kg P ha^{-1} annually	4.03	133
80 kg N ha^{-1} and 30 kg P ha^{-1} annually	6.28	207

Source: UAC, 1980/81; Temu, 1992.

Table 5. Maize yields (t ha^{-1}) with different combinations of farmyard manure (FYM) and compost manure (CM), with inorganic fertilizer (nitrogen at rates of 0, 60 and 120 kg N ha^{-1}) (Uyole, mean of four years' data 1984-1988)

	N0	N60	N120
Control	2257	2805	3040
5t ha^{-1} FYM	3006	3762	4597
10t ha^{-1} FYM	3094	3724	5528
20t ha^{-1} FYM	3502	3729	5342
5t ha^{-1} CM	3314	3547	4925
10t ha^{-1} CM	3424	3541	5296
20t ha^{-1} CM	4168	4382	5654

Phaseolus beans. Trials to evaluate the effect of organic manures on bean yield were conducted at UAC from 1983 to 1987, and at Mbimba in the 1986/87 season. Two rates (5 t and 10 t ha^{-1}) of farmyard and manure compost were used with nitrogen and phosphatic fertilizers. The resulting bean yields data are shown in Table 6. As in the case of maize, application of manure increased yields markedly at both sites. However, the response was greater at Mbimba (soil pH of 5.5) than at Uyole (soil pH 6.2). Stephens (1969), working in Uganda, also reported a greater response to manure application in soils with a low in Ph. A combination of organic manure and chemical fertilizer resulted in higher yields than organic manure alone, again suggesting the complementarity of the two types of fertilizer. The highest yields were obtained when 25 t ha^{-1} of organic manure, were combined with 30 kg N ha^{-1} and 30 P kg ha^{-1}. There was little difference between the two types of organic manure, in contrast to the maize trials. Under the conditions at Morogoro, Rweyemamu and Ndunguru (1984) obtained the highest yields with a moderate application of organic manure (7.5 t ha^{-1}) together with an intermediate rate of nitrogenous and phosphatic fertilizers (25 kg N ha^{-1} and 10 kg P ha^{-1}).

The residual effect of organic manure application on the two crops (maize and beans) was monitored throughout the experimental period. The beneficial effects generally observed lasted until the third year after application, after which yield reductions ranged between 23 and 75%. Re-application of manure in the fourth year dramatically increased yields, suggesting that farmers need to make fresh applications every three or four years if the initial rate is of the order of 20 t ha^{-1} (Temu, 1992). These findings differ from those of Peat (1953) who observed residual effects up to eight years later in Sukumaland (Lake Victoria zone) with maize, cotton and groundnuts, probably as a result of differences in agro-ecological conditions. Residual effects are probably due to the gradual supply of small amounts of several nutrients over a long period of time (Wortman and Zake, 1988).

Table 6. Effects of farmyard manure and compost on yields of *Phaseolus* beans (kg ha^{-1}). Mean of four years' data at UAC, 1983-1987; and one season at Mbimba, 1986-1987)

Treatment	UAC	Mbimba
Control	1021	786
5 t ha^{-1} FYM	1292	1265
10 t ha^{-1} FYM	1652	1180
5 t ha^{-1} CM	1461	1133
10 t ha^{-1} CM	1765	-
NP (30 kg N ha^{-1} + 30 kg P ha^{-1}, the recommended rates)	1730	1421
5 t ha^{-1} FYM + NP	1778	1668
10 t ha^{-1} FYM + NP	1615	1326
5 t ha^{-1} CM + NP	1963	1760
10 t ha^{-1} CM + NP	1705	1515

Effect of method of manure application on maize yield. The effects of application method were evaluated at Uyole from 1983 to 1987. The manures were broadcast and left on the surface, broadcast and incorporated into the soil, or placed under the seed. Placing the manures under the seed resulted in much higher maize yields than applying them to the surface or incorporating them into the soil (Table 7). These findings are in contrast with those from experiments with beans in Kenya where broadcast application gave better results than application under the seed (GLP 1980-1982).

Table 7. Yield of maize (kg ha^{-1}) with different methods of farmyard manure (FYM) and compost (CM) application (mean of four years' data)

	Yield
Control	3136
FYM broadcast and left on surface	4094
FYM broadcast and incorporated into soil	4581
FYM placed under seed	5098
CM broadcast and left on surface	4309
CM broadcast and incorporated into soil	4662
CM under seed	5043
120 kg N ha^{-1} and 20 kg P ha^{-1}	4947

Economics of manure use. The limited data available do not permit precise analysis of the costs and benefits of using organic manures. The data presented in Table 4 indicate that 5 t ha^{-1} FYM can support higher maize yields than those obtained with 40 kg N ha^{-1} plus 15 kg P ha^{-1}, that is, that 1 t ha^{-1} FYM is more than equivalent to 8 kg N ha^{-1}. The data presented in Table 5 indicate that 5 t ha^{-1} FYM or compost can support higher maize yields than those obtained with 120 kg N ha^{-1}, that is, that 1 t ha^{-1} FYM or compost is equivalent to about 24 kg N ha^{-1}. From all the available data for maize from the two sites, Uyole and Mbimba, a conservative estimate is that 1 t ha^{-1} of organic manure is roughly equivalent to 15 kg N ha, although the synergistic effect of inorganic and organic fertilizers, shown in Table 5, implies that there is no simple equivalence between organic and inorganic fertilizers. One bag of calcium ammonium nitrate (CAN), which supplies 13 kg N, can be expected to cost about 2500 TSh (including costs of transport over 20 km to the 'farm-gate', trader fee and cost of application late in the 1992/1993 season when all subsidies are removed), which gives a total cost of 192 TSh per kg N (300-400 TSh = US$ 1 in 1991-92, very approximately). Thus, if organic manure is used to replace some or all of the inorganic nitrogen used by a smallholder, its cost should not be more than 2900 TSh per tonne (including transport and application costs). Informal enquiries around Uyole suggest the price structure shown in Table 8 for FYM purchased in November 1992, prior to maize planting.

It appears that the price range is such that the use of FYM to replace some or most of the inorganic nitrogen required for maize will be economically advantageous in the 1992/93 season.

A multiple quadratic equation fitted to the complete data set summarized in Table 4 for Uyole is shown in Figure 1. The fitted equation is:

$$Y = 2100 + 9.27N - 0.03N^2 + 119.7F - 4.25F^2 + 0.26NF \qquad (1)$$

$$R_{30} = 0.586$$

where Y is maize seed yield (kg ha^{-1}), N is inorganic nitrogen applied (kg ha^{-1}), F is farmyard manure applied (kg ha^{-1}), and R is the multiple correlation coefficient. The multiple correlation coefficient is significant at $P<0.01$, but is not very high. However, this provides a useful way of analysing the response to nitrogen and farmyard manure in mathematical terms. Equation 1 implies that the response to FYM is at a maximum at 14 t ha^{-1} farmyard manure when no inorganic nitrogen is applied, increasing to 18 t ha^{-1} when 120 kg N ha^{-1} is applied.

The predicted net crop value (assuming 60 TSh per kg maize) for different combinations of nitrogen and farmyard manure, plotted against the cost of the nitrogen and farmyard manure, calculated from Equation 1, using the prices already given (50 kg of CAN at 2500 Tsh and 1 t FYM at 2900 TSh) is shown in Figure 2. For these price conditions, the best options, that is, combinations of nitrogen and farmyard manure that give the highest yield and net crop value for a given input cost, are identified by the line shown in Figure 2. This analysis suggests that for Uyole, no more than one bag ha^{-1} of CAN should be applied without FYM; one to four bags of CAN should be applied with 2 t ha^{-1} FYM; four to seven bags should be applied with 4-6 t ha^{-1} FYM; and 7-9 bags with 8 t ha^{-1} FYM. For this soil type and price conditions, application of more than 8 t ha^{-1} FYM is not economically justifiable. The limited data from this one site suggest that, on the basis of returns to cash invested, the application of up to 8 t ha^{-1} FYM is justified if it can be obtained and applied at a price of between 2000-5000 TSh ha^{-1}. However, the supply of inorganic fertilizer has rarely, if ever, been sufficient to meet demand in the Southern Highlands in recent years. When inorganic fertilizer is not available, the data support the use of up to 15 t ha^{-1} FYM, if it can be obtained and if labour for its application is available, to maximize yields. The cost and labour involved in using FYM will almost certainly be justified for most smallholders, whose overwhelming priority is to maximize food security through maize production in nearly all cases (ASSP, 1992).

Table 8. Costs involved in applying farmyard manure (Uyole, 1992)

	Cost (TSh)
5 t FYM	3000-5000
Lorry hire (20 km)	2000-3000
Loading and Unloading	500-1500
Application	4000-8000
Cost per tonne FYM applied	1900-3500

Geological materials

The effect of rock phosphate materials from Mbeya district were evaluated at several locations in Mbeya, Rungwe and Mbozi Districts from 1988 to 1991, using maize and beans as test crops. The experiments were designed to meet the following objectives: to determine the optimum rate and best method of rock phosphate and triple superphosphate application, to investigate the residual effect of the materials; and to monitor the soil reaction and base status after application.

Phosphatic rocks were collected from Panda Hill in Mbeya District. The Panda Hill rock materials, together with Minjingu rock phosphate, were analysed for their chemical properties after having been ground to pass through a 60-80 mm mesh sieve (Table 9). Five sites were chosen for the field experiments: Uyole, Ihanda, Majengo, Mitalula and Mbimba. Soil samples from the experimental sites were collected and analysed for their physical and chemical properties at the beginning of the experiment (Table 10) and at crop harvest. The ground phosphatic material was applied in the first year of the experiment and the residual effects evaluated in subsequent years. Nitrogen was applied as recommended for maize and beans.

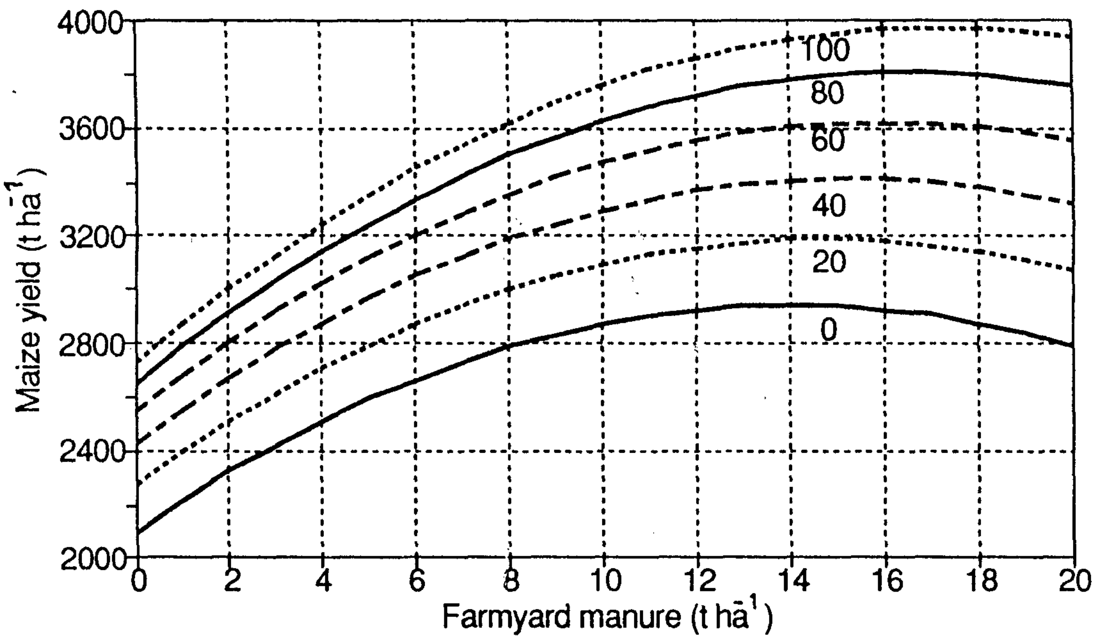

Figure 1. Predicted maize yields for different combinations of farmyard manure and inorganic nitrogen fertilizer (kg ha at Uyole

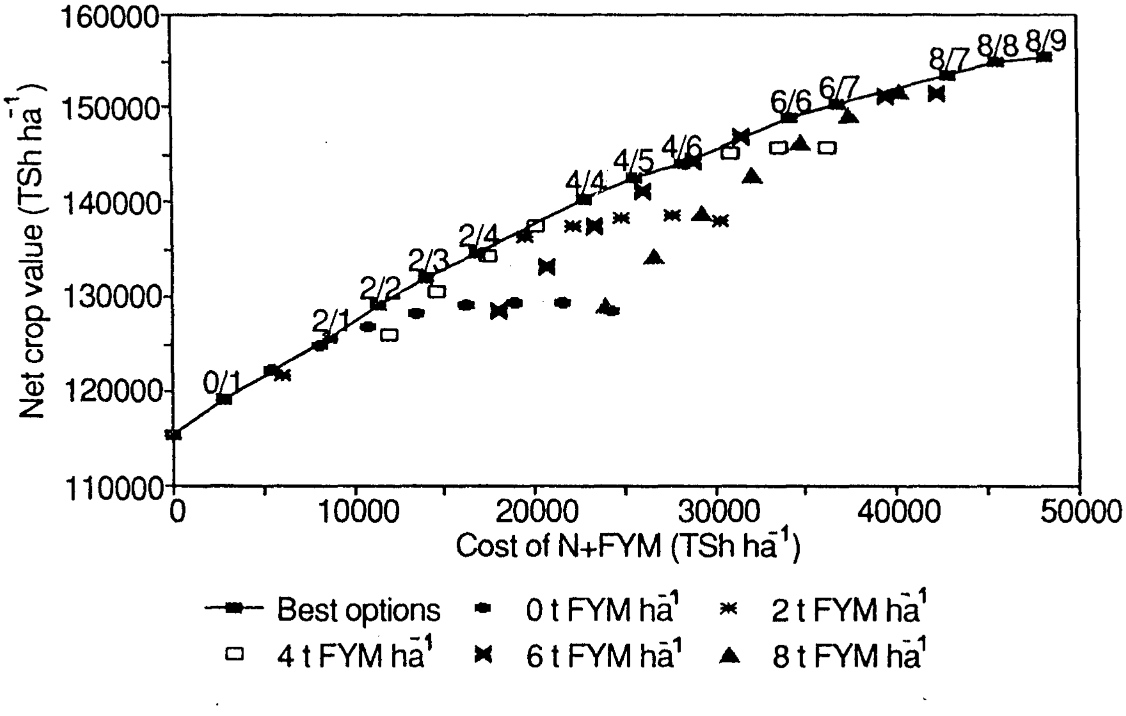

Figure 2. Predicted net crop values for different combinations of farmyard manure and inorganic nitrogen fertilizer. Numbers refer to t ha^{-1} farmyard manure, and 50 kg bags of calcium ammonium nitrate

Table 9. Chemical composition of Panda and Minjingu phosphate rocks

	Minjingu	Panda
Total P_2O_5	34.80	18.00
NAC	2.86	1.60
CaO (%)	46.40	26.70
MgO (%)	3.40	1.30
Na_2O (%)	0.84	1.90
K_2O (%)	1.40	4.10
MnO (%)	0.04	0.65
SiO_2 (%)	10.40	48.10
Al_2O_3 (%)	2.30	15.10
Fe_2O_3 (%)	1.00	12.40
Neutralizing value (%)	-	2.50

Table 10. Soil properties of the study areas before the start of the experiment

Parameter	Ihanda (Ultisol)	Majengo (Oxisol)	Uyole (Inceptisol)	Mitalula (Ultisol)	Mbimba (Inceptisol)
pH (water)	5.6	4.8	6.2	5.8	5.5
Organic C (%)	1.7	1.6	1.9	1.4	1.9
Bray P (ppm)	3.5	1.8	8.0	9.1	2.2
Exch. cations (me 100 g^{-1})					
Ca	2.4	-	2.4	2.2	2.9
Mg	2.5	0.8	1.4	2.4	1.8
K	0.2	0.2	-	0.2	nd
Al	-	1.5	-	-	nd
CEC (me 100 g^{-1})	19.0	nd	20.0	18.5	18.0
Clay (%)	55.0	nd	27.0	26.0	28.0

nd, not determined.

Effect on maize yields and relative agronomic effectiveness (RAE). Panda rock phosphate (PRP) and triple superphosphate (TSP) were each evaluated at 0, 40, 80 and 120 kg P ha^{-1} at Uyole, Mbimba, Majengo and Ihanda (Table 11).

Application of the fertilizers generally increased maize yields, but response varied from location to location and with the source of phosphorus. Yields of maize increased with increasing rate of applied phosphorus. Phosphate at 80 kg ha^{-1} as PRP and TSP gave the highest yield of maize. TSP was superior to PRP in overall yield response at all sites except Mbimba. When increases in yield were averaged over two years for all levels of phosphorus, PRP was found to give 88% of the yield increase of TSP per unit of phosphorus.

When the residual effects were examined two years after application, PRP demonstrated a greater residual effect, especially at 120 kg P ha^{-1}. Rwechungura (1992) found that rock phosphates were inferior to TSP in the first year of application, but had greater residual value (in terms of yield) in the second and third years of cropping. The much greater yields response from the application of soluble forms of phosphorus (such as TSP) than from the insoluble ones (such as PRP) in the first year are due to the greater availability of phosphorus to the crop from the soluble forms.

The Relative Agronomic Effectiveness (RAE) of the PRP was calculated as shown in Equation 2.

$$RAE = \frac{Y_{RP} - Y_0}{Y_{TSP} - Y_0} \qquad (2)$$

where Y_{RP} is the yield at a given rate of phosphate supplied by PRP, Y_{TSP} is the yield at the equivalent phosphate level supplied by TSP, and Y_0 is the yield without phosphate.

An RAE value of more than one indicates that rock phosphate results in higher yields than TSP. Averaged over all phosphorus levels, RAE varied with site and soil between 0.57 and 1.25 (Table 12). RAE varied little with phosphorus level. The high RAEs on the acid soils of Mbimba and Ihanda confirm the findings of Khaseweh and Doll (1978) and Rweyemamu (1989) who also observed that rock phosphates are most effective in acid (pH less than 6.0) and phosphorus deficient soils. However, the poor response at Majengo was unexpected, and was probably due to the extremely high phosphorus adsorption capacity of the soil of the area, as recently reported by Mnkeni (1992 - personal communication). The results suggest that 40 kg ha^{-1} P (five bags per hectare PRP) is the best rate for farmers to apply, giving long-term yields similar to those resulting from the use of TSP.

Table 11. Mean (2 yr) effects of ground Panda phosphate rock and TSP on maize yield (t ha^{-1}) at four sites

kg P ha^{-1}	Majengo	Mbimba	Uyole	Ihanda	Mean
0	1.3	2.8	2.2	2.8	2.3
TSP					
40	2.3	3.5	3.5	3.3	3.2
80	2.5	3.9	3.2	3.7	3.3
120	3.2	3.4	3.2	4.2	3.5
Panda rock phosphate					
40	2.0	3.8	2.9	3.5	3.1
80	2.0	3.5	3.2	3.5	3.0
120	2.2	3.9	3.2	4.0	3.3
Mean	2.0	3.4	2.9	3.4	2.9
F value	14.8*	NS	NS	3.1*	-

* Significant at P<0.01

Table 12. Relative agronomic effective-ness (RAE) of rock phosphate on maize at four locations

Location	P (kg ha^{-1})		
	40	80	120
Majengo	0.68	0.55	0.47
Mbimba	1.34	0.62	1.79
Uyole	0.55	0.97	1.03
Ihanda	1.62	0.79	0.84

Effect on bean yields and relative agronomic effectiveness. The response of beans to PRP and TSP was compared at 0, 15, 30 and 45 kg P ha^{-1}, at Uyole from 1988 to 1990. All fertilizer treatments gave higher bean yields than the control treatment (without fertilizer) in both seasons (Table 13).

As in maize, the response was higher in the second than in the first especially where PRP was applied. On average, 45 kg P ha^{-1} either supplied as PRP or TSP gave the best yield of beans. Promising results were obtained with 15 kg P ha^{-1} as PRP, particularly in the second year of application. PRP was more effective than TSP in the second year after application, mainly because the residual effects lasted longer (Table 14). Taking account of these longer term effects, 15-30 kg P ha^{-1} as PRP appears to be the best rate for beans.

Table 13. Effect of Panda rock phosphate on the yield (t ha^{-1}) of *Phaseolus* beans at UAC

P (kg ha^{-1})	1988/89	1989/90
0	1.2	1.9
TSP		
15	1.5	2.7
30	1.5	2.9
45	1.5	3.1
Panda rock phosphate		
15	1.2	3.0
30	1.3	2.9
45	1.2	3.3
F value	NS	*

NS difference not significant; * denotes a significant difference at $P<0.05$

Table 14. Relative agronomic effectiveness (RAE) of rock phosphate on beans

P (kg ha^{-1})	1988/89	1989/90
15	0.14	1.41
30	0.33	0.92
45	0.19	1.14

Effect on soil properties. There was a wide variation in soil physio-chemical properties before the start of the experiments, as shown in Table 10. When changes in soil properties were monitored three/four years after the application of phosphatic fertilizers (PRP and TSP) it was evident that the response varied from site to site. A marked increase the phosphorus available in the soil as a result of phosphorus application was observed at all the sites. The increase was particularly high at Majengo, where the available phosphorus increased from 1.4 to well over 20 ppm, although this was not reflected in the yield of maize. PRP had a greater effect on available phosphorus than TSP at all sites. However, annual monitoring of phosphorus revealed a considerable reduction in available phosphorus in the third year of cropping, in some instances below the critical levels for many crops, emphasizing the need for re-application of rock phosphate in the third or fourth year after the initial application. Changes in soil pH were generally inconsistent, except at Majengo where a tremendous improvement in pH was noticed (from pH 4.8 to 6.0) with PRP. This may have been due to the liming effect of PRP (Mughogho, 1988).

Methods of Panda rock phosphate and TSP application. From 1989 to 1991 three methods of rock phosphate and TSP application were investigated at Uyole, Mbimba and Mitalula using maize as a test crop: broadcast, applied in rows (banding), and applied 5 cm under the seed. The effect on maize yields is shown in Table 15.

Although the overall performance was influenced by site and season, in general the application of rock phosphate and TSP, either in the row or 5 cm below the seed resulted in appreciable increases in maize yields compared with broadcast application. De Geus (1976) recommends band placement methods (in the row or under the seed) for rock phosphate, particularly on soils where it rapidly becomes fixed in unavailable phosphorus forms, and when relatively small quantities of fertilizer are needed.

Estimating the costs of rock phosphate. The 1992/93 retail price of TSP is expected to be 2736 TSh for a 50 kg bag, which when trader fees, transport costs and application costs are added, gives a cost of 412 TSh per kg of phosphorus applied (Table 16). Rock phosphate gave similar yields to those of TSP when averaged over two years, thus the price of rock phosphate per unit of phosphorus should be similar if the material is to be attractive to farmers. This implies that rock phosphate would have to be retailed at about 758 TSh bag at 1992/93.

Table 15. Effect of Panda rock phosphate (PRP) and triple superphosphate (TSP) application methods on maize yields (t ha^{-1}) at three locations (means of two years)

	Mbimba	Mitalula	Uyole
Control (no P)	2.8	4.1	3.1
Broadcast PRP	2.3	4.5	3.7
Row applied PRP	3.4	4.6	3.5
Under seed PRP	3.5	4.3	3.9
Broadcast TSP	3.4	4.5	4.0
Row applied TSP	3.7	4.5	3.9
Under seed TSP	3.7	4.5	3.9
Mean	3.4	4.4	3.8

Table 16. Calculation of the retail price (TSh) of rock phosphate (RP) if it is to compete with triple superphosphate (TSP) as a fertilizer

	TSP	RP
Cost per kg P applied	412	412
P content (kg) per 50 kg bag	10	4
Cost per bag	4120	1648
Application cost per bag	100	100
Transport cost per bag	600	600
Trader fee per bag (20%)	684	190
Retail price per bag	2736	758

Organic Manures

Increased coverage of soil-types, climatic conditions and crop types. The responses to organic manures reported here are unlikely to be applicable in drier and warmer areas of the Southern Highlands, particularly in the low altitude areas, where higher temperatures are likely to increase decomposition rates and limit residual effects. Accordingly, there is a need for research in the low altitude areas, to determine optimum rates and combinations of organic and inorganic fertilizers. The area covered by research at mid and high altitude is also extremely limited and should be increased. This research should perhaps take priority over research in the low altitude areas, where the responses are likely to be smaller. *Phaseolus* beans, as a leguminous crop, showed less response per tonne of manure than maize, highlighting the need to evaluate the effect on other major cash and food crops to enable smallholders to prioritize the use of organic manure in circumstances where the supply is less than the demand.

Development of preparation and application methods suitable for smallholder farmers. Although the preparation of compost is not technically complex, there is a need to evaluate different methods in collaboration with farmers, to adapt methods to smallholder conditions. The main problem with the use of farmyard manure is one of logistics, and research cannot help very much in this area. However, a multi-disciplinary approach, with a research team that includ livestock scientists, could be used to examine alternative animal management strategies, and to evaluate the benefits and possible disadvantages of strategies that give improved access to manure.

Evaluations of the economics of manure use, and the equivalence between organic and inorganic materials. The desirability of using organic materials is accepted by virtually everyone involved in crop production, but there is a need to evaluate the benefits, both short and long term, against other activities to enable farmers and extension workers to assign priorities to the use of organic materials in comparison with other demands on smallholders limited labour and cash resources. The synergistic effect of organic and inorganic materials implies that recommendations on the use of inorganic fertilizers should be modified according to the levels of use of organic materials possible for different smallholder groups. Ideally, research and extension workers should develop a range of recommendations combining both organic and inorganic fertilizers for different agro-ecological zones and crops, to enable village extension workers to provide advice precisely targeted to the circumstances of individual smallholders.

Geological materials

The data presented indicate that rock phosphates available in Tanzania could replace much of the current consumption of TSP, thereby reducing the foreign exchange demand of the agricultural sector. The most pressing need is the development of a manufacturing base for producing and packaging the rock phosphates, so that they can be supplied at an economic rate. However, additional research is required, particularly farmer evaluation trials. Yield responses in the first year of application were generally not very high. This could pose a serious limitation to adoption by resource-poor farmers. Training and demonstrations are obviously needed, but they are much more likely to be successful if designed in collaboration with the farmers. Assuming that farmer evaluations are favourable, there is a need for policy research, to evaluate the possible benefit to the nation of subsidizing rock phosphate production to reduce foreign exchange costs. In addition, the interactions between rock phosphates and organic manures on acid soils should be studied.

CONCLUSIONS

Large increases in maize and bean yields in response to organic manure application have been observed. In some cases the responses have been equal to those resulting from the use of artificial fertilizers in the year of application, with significant residual effects for up to four years after application. Combinations of organic manures (farmyard manure and compost) and inorganic fertilizers resulted in synergistic yield increases, such that crop yields were higher when both were applied than when either was applied alone. Ideally, organic materials should be seen as supplements to inorganic fertilizers rather than replacements for them, although the removal of subsidies on inorganic fertilizers is likely to make use of organic manures more attractive to farmers in economic terms. Placement of the manure under the seed was found to give the best results in terms of crop yield.

Currently, there is insufficient data to develop precise recommendations for the use of organic manures. However, the limited data available suggest that for the mid to high altitude areas, application of up to 20 t ha^{-1} organic manure will be economically justifiable for maize production, and up to 10 t ha^{-1} for bean production, providing the material can be obtained and applied at a cost of between 2000-5000 TSh a tonne. Clearly, there is a need for further studies to develop optimum combinations of organic and inorganic fertilizers for different investment costs and agro-ecological zones, particularly for the low altitude areas of the Southern Highlands.

Rock phosphates could prove a suitable alternative to imported fertilizer, particularly in acid and phosphorus deficient soils and in the second or third year after application. Applying rock phosphate 5 cm under the seed or in bands in the row resulted in much higher yields of maize than broadcast application. Provided that Panda rock phosphate could be retailed at about 750 TSh per 50 kg bag, 40 kg ha^{-1} would be the optimum rate for maize on acid soils, and 15 kg P ha^{-1} would be the optimum rate for beans.

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