Nutrient Cycling in Agroecosystems **48:** 179–189, 1997.

Agronomic and economic evaluation of Tilemsi phosphate rock in different agroecological zones of Mali

A. Bationo[1], E. Ayuk[2], D. Ballo[3] and M. Koné[4]
[1]*IFDC/ICRISAT, BP 12404, Niamey, Niger;* [2]*ICRAF/ICRISAT, BP 320, Bamako, Mali;* [3]*SRCFJ, N'Tarla, Mali;* [4]*IER-Sikasso, Mali*

Received 21 November 1995; accepted in revised form 31 December 1996

Key words: agronomic and economic evaluation, cropping systems, indigenous phosphate rock

Abstract

Phosphorus deficiency is known as one of the major constraints to crop production in West Africa. Farmer-managed trials were conducted in three agroecological zones of Mali to evaluate the profitability of Tilemsi phosphate rock (TPR) in different crop-rotation systems in comparison with conventional water-soluble fertilizers. Marginal analyses were used to compare treatments tested. Results show that crop yields using TPR are comparable to those of recommended cotton- or cereal-complex imported fertilizers. The economic evaluation also clearly indicated that direct application of TPR is relatively profitable in comparison with recommended imported fertilizers and that good management enhances the profitability of fertilizers in general.

Introduction

Phosphorus deficiency is one of the major constraints to crop production in West Africa. For many years now, research has been undertaken to assess the extent of soil phosphorus deficiency, to estimate the phosphorus requirement of major crops, and to evaluate the agronomic potential of various phosphate fertilizers including phosphate rock (PR) from local deposits [2, 5, 6, 14, 17, 21, 20, 10, 19]. In the drier zones of Mali, Traoré [18] reported that crop response to N was minimal or sometimes completely non-existent until P requirements had been satisfied.

Although the beneficial effects of P fertilizers are widely known, lack of adequate financial resources limit their use by West African farmers. Direct application of indigenous PR can be an economic alternative to the use of imported and more expensive water-soluble P fertilizers and would allow savings in much needed foreign exchange.

The effectiveness of PR depends on its chemical and mineralogical composition, soil factors, and the crops to be grown [8]. Diamond [4] proposed a classification of phosphate rock for direct application based on cirate-solubility: >5.4% (high); 3.2-5% (medium); and <2.76% low. According to this classification, PR from Matam (Senegal), Tilemsi (Mali) and Tahoua (Niger) are medium in reactivity. Truong et al. [20] compared several PR sources (Anecho in Togo, Arli and Kodjari in Burkina Faso, Tahoua in Niger and Taïba in Senegal) and found that only Tahoua and Tilemsi PR (TPR) were suitable for direct application. Previous research [11, 12, 13, 19, 20, 22] has also provided information on the agronomic value and efficiency of direct application of TPR. Thibout et al. [19] investigated the use of TPR on food and oil seed crops in Mali in on-station trials undertaken during the period 1969-77 at research stations in Sotuba, Kita, Seno and Sikasso. They found that TPR is agronomically efficient when applied directly.

In Mali, recent work [15] by the Institut d'Economie Rurale (IER) and the International Fertilizer Development Center (IFDC) clearly indicated that TPR can result in net returns and value-cost ratios similar to those of triple superphosphate (TSP). These results are based on researcher-managed trials undertaken in different agroecological zones of the country. Kagbo [7] using data from on-farm trials conducted by the "Operation Haute Vallée" project found that using local rock phosphate instead of imported cotton fertilizer was more profitable, especially for the maize-cotton rotation. Except for the study by Kagbo [7], little research has been undertaken on evaluation of the agronomic and economic value of indigenous PR under farmers' conditions.

The purpose of this study is to evaluate at farm-level, both agronomically and economically, TPR under farmers' operating conditions.

Materials and methods

Phosphate rock deposit

Tilemsi phosphate rock deposits in Mali are located in the Tilemsi Valley near In-Tassit and estimated to be between 20 and 25 million tonnes. The rocks contain P_2O_5 in the range of 23% and 32%. The neutral ammonium citrate of Tilemsi PR is 4.2%. Since 1976, these deposits have been mined at the rate of about 2,000 Mg per year, and a mill capable of processing up to 30,000 Mg per year is operational [9].

Farmers' evaluation of Tilemsi phosphate rock

To evaluate TPR under the farmers' conditions, firmer-managed trials were conducted in three agroecological zones and for three cropping systems in Mali. The cropping systems included: a rotation of groundnut and pearl millet at Tafla (600 mm rainfall), a rotation of cotton and sorghum at Sougoumba (800 mm rainfall) and a rotation of cotton and maize at Tinfounga (1,200 mm rainfall).

In each of the 3 villages, 30 farmers were chosen randomly from a group of farmers who were willing to participate in on-farm experimentation. Participating farmers provided land in their farms where four 25 m$\times$25m plots were laid out. One of the plots was split in two for T1 and T2, and the other three treatments were randomized in the remaining plots. They were provided with fertilizers and were allowed to manage the test plots as they deemed necessary. For each village fifteen started with the cereal crop (pearl millet in Tafla; maize in Tinfouga; sorghum in Sougoumba and the other fifteen with the cash crop (groundnut in Tafla; cotton in Sougournba and Tinfounga). Over the four-year period (1989-1992), there were therefore two groups of 15 farmers in each village following a specific rotation. None of the farmers dropped out during the period of this study.

The following treatments were used :

T1: Absolute control, no fertilizer is applied (AC);
T2: Farmers' practices where farmers apply the quantity of fertilizers according to their accustomed practices (FP);
T3: Recommended levels of water-soluble fertilizers according to the extension services in Mali (RP);
T4: Annual direct application of Tilemsi phosphate rock (TPRA);
T5: One-time (basal) direct application of (TPRB).

Table 1 shows the rates of N, P, K and S applied for the different treatments and crops during the period of study. It is important to distinguish between T2 and T3. In T2 farmers do not, for instance, apply urea on the maize crop according to recommended practices. The basal application dose (T5) was three times (in Tafla) and two times (in Sougoumba and Tinfouga) the annual application rate (T4). The annual application rate itself was selected as the optimum rate established as per previous on-station research in Mali and recommended by extension services. The basal rate was used to study the residual effect of indigenous PR.

Resident field assistants were posted on a full time basis to monitor all crop management practices of individual farmers, rainfall events, and socio-economic characteristics of the production environment. Senior national scientists and IFDC-Africa staff backstopped the field assistants through frequent visits.

Before the first application of fertilizers, surface soils (0-20 cm) were sampled in the trial plots. The soil analysis are reported in Table 2. The average organic matter content of these soils ranged from 0.41% in the Semi-arid agroecological zone of Tafla to 1.31% in the Northern guinea savannah zone of Tinfounga. The soils are slightly acidic and very poor in available phosphorus.

Economic analysis

To determine the profitability of the different strategies over the period of study two approaches were used: marginal analysis and partial budgeting. Both methods are discussed extensively in CIMMYT [3]. Marginal analysis involves the process of calculating the marginal rates of return between treatments, proceeding in steps from lower cost treatment to that of higher cost (CIMMYT, 1988, p38). First, the total costs that vary are calculated for each treatment together with their net benefits (gross benefits minus total cost that vary). Secondly, the alternative strategies are arranged in order of increasing costs. To simplify the analysis a

Table 1. Quantities of NPKS fertilizers (kg nutrients ha^{-1}) applied at different sites in Mali (1989-1992)

Site/Crop		Year											
		1989			1990			1991			1992		
		T3[a]	T4	T5	T3	T4	T5	T3	T4	T5	T3	T4	T5
Sougoumba/Cotton	N	44	46	46	44	46	46	44	46	46	44	46	46
	P	33	55	82.5	33	55	0	33	55	82.5	33	55	0
	K	18	19	12	18	19	12	18	19	12	18	19	12
	S	12	7	7	12	7	7	12	7	7	12	7	7
Sougoumba/Sorghum	N	7	23	23	7	23	23	7	23	23	7	23	23
	P	11	27	82	11	27	0	11	27	82	11	27	0
	K	6	0	4	6	0	4	6	0	4	6	0	4
	S	4	0	0	4	0	0	4	0	0	4	0	0
Tafla/Groundnut	N	12	27	27	12	27	27	12	27	27	12	27	27
	P	12	27	82	12	27	0	12	27	0	12	27	82
	K	6	0	0	6	0	0	6	0	0	6	0	0
	S	4	0	0	4	0	0	4	0	0	4	0	0
Tafla/Millet	N	14	23	23	14	23	23	14	23	23	14	23	23
	P	22	27	82	22	27	0	22	27	0	22	21	82
	K	12	0	0	12	0	0	12	0	0	12	0	0
	S	4	0	0	4	0	0	4	0	0	4	0	0
Tinfouga/Cotton	N	44	46	46	44	46	46	44	46	46	44	46	46
	P	33	55	82	33	55	0	33	55	82	33	51	0
	K	18	19	12	18	19	12	18	19	12	18	19	12
	S	12	7	7	12	7	7	12	7	7	12	7	7
Tinfouga/Maize	N	83	83	83	83	83	83	83	83	83	83	83	83
	P	22	27	82	22	27	0	22	27	82	22	27	0
	K	12	12	8	12	12	8	12	12	8	12	12	8
	S	8	4.5	4.5	8	4.5	4.5	8	4.5	4.5	8	4.5	4.5

[a] T3 : Recommended practice; T4: Tilemsi PR Annual; T5: Tilemsi PR Basal (one-time)

Table 2. Chemical soil properties of the field plots of participating farmers

	Tafla		Sougoumba		Tinfouga	
	Range	Average	Range	Average	Range	Average
Organic matter (%)	0.26-0.69	0.41	0.45-0.19	0.71	069-2.66	1.31
Total nitrogen (mg kg^{-1})	153-316	204	196-483	307	301-858	5.22
Available P (Bray P1)(mg kg^{-1})	1.08-6.87	3.2	1.44-14.20	5.34	1.54-14.2	5.48
Soil pH (KCl)	4.08-6.18	4.85	4.40-6.00	4.83	4.43-5.68	4.89

treatment with a higher cost but lower net benefits than the preceding treatment is said to be dominated and is removed from the analysis. Finally, the marginal rate of return is obtained by calculating the ratio of net benefits to total costs that vary for adjacent treatments to determine the treatment with optimal aggregate return.

The marginal rates of return provide a useful tool in determining the best fertilizer treatment. A particular issue of interest in this study was to determine how the different options compare to each other. For this, a partial budget analysis approach was used. Partial budgeting is similar to marginal analysis described above and involves taking into consideration only the incremental costs associated with a particular treatment. For each treatment variable costs, mainly the cost of fertilizers, were calculated. Average farm gate prices during the study period were used to estimate the gross benefits for each treatment. On the basis of the variable costs and benefits, net gains for each pair of treatments was defined as follows :

$$NG_{ij} = B_{ij} - C_{ij}$$

Where NG is the net gains of treatment j when compared to treatment i, B is the additional benefit of treatment j over treatment i, and C is the additional cost of treatment j over treatment i. This approach involves a pairwise comparison of all available options.

For all pair-wise comparisons a symmetric matrix (in absolute terms) of net gains is developed. Symetry implies that the net gains of treatment i when compared to treatment j is the same as the net gains when treatment j is compared to treatment i. This method enables us to compare the relative profitability of any two treatments of interest. A negative sign on NG_{ij} denotes that treatment i which is the row treatment dominates (more profitable than) treatment j, the column treatment.

There were data for the same number of years for each crop at each site. Consequently, the data were pooled over the four-year period to obtain average returns. Costs of fertilizers for each treatment were based on yearly costs of corresponding treatments.

Results and discussion

Agronomic evaluation

The effect of the different fertilizer treatments on yields of groundnut, pearl millet, sorghum, maize and cotton are presented in Table 3. The results show that except for millet and groundnut in the Sahelian zone at Tafla, all the treatments increased crop yields significantly over the absolute control treatment. The results in Tafla are probably due to the fact that some drought was experienced at this site. Crop yields using TPR are as high as those of recommended cotton- or cereal-complex imported fertilizers There was no significant difference in crop yields between annual and one-time (basal) application of TPR.

For these farmer managed trials large differences between farmers for the same treatment were found. To be able to understand these differences, the influence of management practices, rainfall, and soil physical

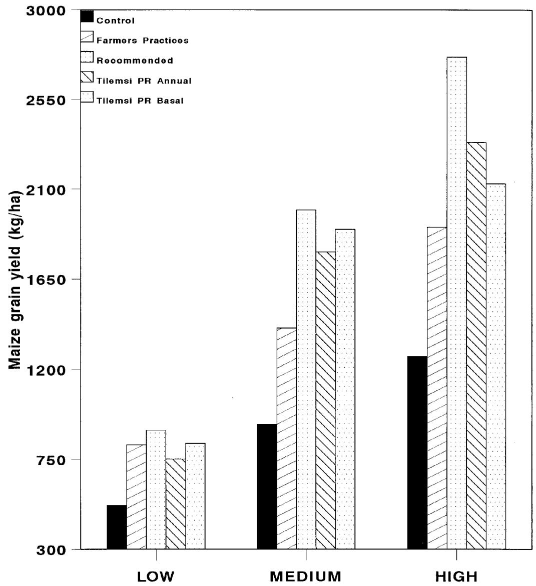

Figure 1. Management by environment interaction. Effect of crop management, soil organic matter and rainfall on maize grain yield at Tinfouga, Mali.

and chemical characteristics on the yield for a given treatment was analyzed. Regression models were developed for each treatment incorporating management variables, rainfall and certain physical and chemical characteristics of the soils as explanatory variables. Variables used to account for differences due to management practices included planting density, dates of planting and weeding, etc. For soil physical and chemical characteristics, variables such as clay content, organic matter and pH were used. Both total rainfall and quantity of rain received every 30 days after planting were included in the models.

Table 4 summarizes the models developed and the regression equations that related the variables on yield. The goodness of fit measures of R^2 and regression significances suggest that a significant proportion of the variation in crop yields is explained by some of these management variables.

Critical values for low, medium, and high management practices were determined from descriptive statistics of the explanatory variables. Low management would entail, for instance, that the farmer is planting at a very low density for the planting density variable or is planting excessively very late for the date of planting variable. Medium management describes an intermediate position which can still be improved and high management denotes that the farmer is under-

Table 3. Effect of different sources of fertilisers on groundnut, millet, sorghum, maize and cotton different agroclimatotogical zones of Mali (1989-1992)

		Absolute Control	Farmers' Practice	Recommended Practice	Tilemsi PR Annual	Tilemsi PR One-time	LSD	CV (%)
Sougoumba								
Sorghum	1989	993	979	1,275	1,325	1,464	156	18
	1990	955	1,103	1,24	1,365	1,216	215	25
	1991	866	1,134	1,264	1,165	1,210	271	33
	1992	1,036	1,289	1,923	2,207	1,785	162	25
Cotton	1989	1,121	1,351	1,645	1,610	1,691	190	17
	1990	731	1,013	1,223	1,044	1,142	174	23
	1991	1,245	1,428	1,544	1,614	1,564	152	14
	1992	931	1,120	1,307	1,354	1,514	288	18
Groundnut	1989	775	885	844	825	775	112	19
	1990	283	334	361	338	370	67	27
	1991	499	746	591	609	577	107	26
	1992	556	583	695	564	660	109	24
Tafla								
Millet	1989	718	746	894	960	1,039	132	21
	1990	742	995	969	774	914	161	25
	1991	535	664	788	859	1,324	156	??
	1992	254	360	411	349	337	101	40
Tinfounga								
Maize	1989	1,014	1,818	2,296	1,877	2,204	331	25
	1990	723	723	2,725	2,069	2,174	374	6
	1991	1,043	2,193	2,725	2,865	2,509	304	19
	1992	670	2,087	2,712	2,190	2,529	418	28
Cotton	1989	866	1,462	1,595	1,410	1,571	165	16
	1990	1,178	1,997	2,236	2,001	1,982	201	15
	1991	436	761	1,103	954	1,116	160	25
	1992	826	1,461	1,515	1,463	1,479	194	20

taking the necessary activities as recommended. Figure 1 shows predicted yields for the three scenarios for maize production at Tinfouga. It is apparent from these results that ultimate yield was greatly affected by management practices as well as by events such as rainfall, outside the control of the farmers. Even though farmers do not have control over rainfall and cannot easily change their soil organic matter and pH levels, the results strongly indicate that good management practices should be adopted together with the use of fertilizers. Though not formally tested in this study it appears that there is a strong interaction between management practices and fertilizer applications.

Economic evaluation

Economic considerations play an important role in farmers' decisions as to whether or not to adopt a given technological innovation. On the basis of the agronomic data presented above, a financial analysis was undertaken to determine the level of profitability of the different fertilizer treatments.

Table 4. Effect of crop management, rainfall and soil native fertility on crop yields in the different agroecological zones of Mali, 1989-92

Location	Crop	Treatments	Regression equation[a]	Regression significances	R^2
Tafla	Millt	Control	y=127+0.01169D	0.000	0.51
		Farmers' practices	y=423+0.012243D-16788DP	0.000	0.65
		Recommended	y=78-6.799 DPA+9.7464DH	0.000	0.61
		Tilemsi PR annual	y=348-7.5698DP+4.6658DH	0.021	0.41
		Tilemdi PR basal	y=567-14.45DP+4.2492DH	0.005	0.47
	Groundnut	Control	y=138+2.592RF	0.001	0.49
		Farmers' practices	y=213+2.567RF	0.002	0.45
		Recommended	y=243+2.418RF	0.002	0.455
		Tilemsi PR annual	y=221+2.513RF	0.001	0.47
		Tilemsi PR basal	y=274+2.042RF	0.004	0.42
Sougoumba	Cotton	y=-438+0.028827D	0.000	0.53	
		Farmers' practices	y=-563+0.035491D	0.000	0.57
		Recommended	y=-975+0.048026D	0.000	0.68
		Tilemsi PR annual	y=-1.160+0.051489D	0.000	0.69
		Tilemsi PR basal	y=-739+0.045043D	0.000	0.61
	Sougoumba	Control	y=1.283-22.21DP+491.22PH	0.005	0.57
		Farmers' practices	y=732+0.0064588D	0.343	0.18
		Recommended	y=734+0.010416D	0.110	0.30
		Tilemsi PR annual	y=522+0.014535D	0.003	0.52
		Tilemsi PR basal	y=402+0.018485D	0.000	0.60
Tinfouga	Cotton	Control	y=944-8.03007DH+5.6751RF	0.000	0.55
		Farmers' practices	y=2.063-17.165DH+9.947RF	0.000	0.63
		Recommended	y=2.917-32.288DP-28.913DW	0.001	0.54
		Tilemsi PR annual	y=912+0.011787D+8.9091RF	0.000	0.64
		Tilemsi PR basal	y=2.375-28.471 DPA-19.8DW	0.000	0.67
	Maize	Control	y=1.283-19.072DP	0.012	0.37
		Farmers' practices	y=287+0.028912D+441.88DW	0.048	0.37
		Recommended	y=2.356+0.048949D-30.744DPA	0.000	0.55
		Tilemsi PR annual	y=89+0.0264D-64.372DNSI+11.399RF	0.000	0.59
		Tilemsi PR basal	y=1.163+0.034158D+8.1895RF	0.005	0.47

[a] D:Planting density; DP: Date of planting; DPA: Date of phosphorus allpication; DH: Date of harvest; RF: Rainfall, pH: Soil reaction as measured by pH; DW: Date of weeding; DNSI: Date of the first nitrogen split application; OM: Organic matter.

The economic parameters used to undertake the analysis are shown in Table 5 for the period of study. Table 6 consists of marginal rates of return for the various treatments and rotation systems. For Sougoumba it can be observed that direct application of Tilemsi PR either annually or basal dominates the recommended practice. The marginal rate of return of the basal application over the control plot is 104% whereas the marginal rate of return of annual application of Tilemsi PR is 111% in comparison with basal Tilemsi PR. In Tafla, the best option is the one-time direct application of Tilemsi PR. At this site annual application of Tilemsi PR is dominated. In Tinfouga, the recommended practice has the highest net benefits ha^{-1}. The marginal rate of return over the Tilemsi basal dose is 138%. The basal dose has a marginal rate of return of 140% over the control plot. It can be observed in general that as

Table 5. Parameters used for economic analysis (1989-1992)

Variable	Year			
	1989	1990	1991	1992
Crop prices(FCFA[a] kg^{-1})				
Cotton	85	85	95	95
Groundnut	100	60	104	100
Maize	36	40	45	45
Millet	50	50	78	78
Sorghum	36	50	75	75
Fertilizer costs(FCFA kg^{-1})				
Urea	145	100	100	100
Complex cotton[b]	155	155	120	120
Complex cereal[c]	115	105	105	105
Tilemsi PR	30	30	30	30
Potassium	125	125	125	125
Other costs:				
Fertilizer transportation and application[d]	4,200	4,200	4,200	4,200

[a] 50OFCFA = $1.00 (after January 1994, before January 1994: 25OFCFA=$1.00).
[b] Complex cotton contains 14, 22.14, 7, 1% of N, P, K, S and B, respectively.
[c] Complex cereal contains 14, 22, 14 of N, P and K, respectively.
[d] Costs for the recommended practice is 3,50OFCFA year^{-1}.

one goes from the more humid areas to the drier areas, the profitability of fertilizers decreases.

The results of the pairwise comparisons of the different treatments at all study sites are shown in Table 7. The figures represent pairwise comparisons between the column and row strategies. A negative sign denotes that the particular column strategy is dominated by the corresponding row strategy. In Sougoumba the annual direct application of the indigenous PR is the best option followed by one-time direct application of Tilemsi PR and then by the recommended practice. The insight from these data is that if for any reason the farmer cannot follow the annual direct application of the indigenous PR, the second best strategy is the basal dose of Tilemsi PR.

Based on the data from Tafla, basal application of Tilemsi PR is the best option. In the absence of this the recommended practice can be followed. The situation in Tinfouga shows that all fertilizer options are superior to the absolute control treatment. The recommended practice brings in 319,025FCFA ($638.00) over the four-year period, followed by basal application of PR with 278,935FCFA ($558)and lastly annual application of PR with 224,560FCFA ($449.00).

At all three sites a one-to-one comparison between annual and basal application of Tilemsi PR shows that the basal dose of Tilemsi PR is a better option at two sites (Tafla and Tinfouga). The additional benefits over annual application are 36,035FCFA ($12.00) and 54,735FCFA ($109.00) in Tafla and Tinfouga, respectively. At Sougoumba, the difference between annual and basal application doses is 2,66OFCFA ($5.00) in favour of the annual dose.

The importance of adopting good management practices when fertilizers are used has been emphasized in this study. As it was earlier mentioned low, medium and high management refer in part to the timeliness of undertaking varies cropping activities. Net gains were calculated on the basis of the predicted yields where the explanatory variables are management variables for all crops in the test villages. These data are presented in Table 8. Two significant conclusions can be drawn from the data. Firstly, if the farmer is not willing to adopt good management practices, fertilizers should not be used. With the exception of

Table 6. Marginal rate of returns of various fertilizer treatments in different agroecological zones in Mali

Treatment	Cost that vary[a,b]	Net benefits	Marginal rate of return
Sougoumba (Cotton-Sorghum)			
T1: Absolute Control	0	590,290	
			104%
T5: Tilemsi PR Biannual	138,105	733,240	
			-
T3: Recommended Practice	140,250	720,500D[c]	
			111%
T4: Tilemsi PR Annual	140,500	735,900	
Tafla (Groundnut-Millet)			
T1: Absolute Control	0	336,520	
			5%
T3: Recommended Practice	83,335	340,360	
			-
T4: Tilemsi PR annual	91,090	312,350 D	
			38%
T5: Tilemsi PR Triannual	104,530	348,385	
Tinfouga (Cotton-Maize)			
T1: Absolute Control	0	463,140	
			140%
T5: Tilemsi PR Biannual	199,470	742,075	
			-
T4: Tilemsi PR Annual	209,655	687,700D	
			138%
T3: Recommended Practice	228,500	782,165	

[a] All figures are rounded to the nearest 5FCFA.
[b] 500FCFA=$1.00 after January 1994, prior to January 1994: 250FCFA=$1.00.
[c] D denotes that treatment is dominated. That is, there is a preceding treatment, which has smaller costs that vary and larger net benefits.

Tafla and of the recommended practice in Tinfouga, net gains for the control plot are superior to the other treatments at low management level. Secondly, except in Tafla for all treatments, the net gains per hectare increase as the management practice is improved. The drought experienced in Tafla during the study period might explain why Tafla is an exception to the trend observed. Nontheless, in general, the results suggest that good management enhances fertilizer profitability.

On the basis of this study a few key issues emerge. First, the question is whether the financial advantage of Tilemsi PR over conventional imported fertilizers is such that farmers not previously using fertilizers can be motivated to apply Tilemsi PR. Secondly, whether TPR is a substitute for complex cotton and cereal fertilizers. Socio-economic surveys conducted in the study area indicate that the main constraint to the use of fertilizers is high costs [16]. Thus, any fertilizer strategy which is less expensive than conventional fertilizers stands a better chance of adoption. This is especially true for food crops where the input/output price ratio is very high. The same study identifies that the adoption of the finely ground TPR is hindered by the dusty nature of the product in addition to the fact that it provides only phosphorus which means that other elements must be supplied. In recent years the International Fertilizer Development Center (IFDC) and the Institut d'Economie Rurale (IER) have tested several compacted products on station, where TPR is used to replace the P in compound N,P,K,S and B fertiliz-

Table 7. Pairwise comparison of net gains(FCFA ha^{-1}) for different fertilizer treatments in 3 agroecological zones in Mali during 4 years(1989-1992)

	Absolute control (T1)	Recommended practice (T3)[a,b]	Tilemsi PR annual (T4)	Tilemsi PR basal:one-time (T5)
Sougoumba (Cotton-Sorghum)				
Absolute Control(T1)	-	130,210	145,610	142,950
Recommended Practice (T3)		-	15,400	12,740
Tilemsi PR Annual (T4)			-	-2,660
Tilemsi PR Basal: one-time (T5)				-
Tafla (Groundnut-Millet)				
Absolute Control(T1)	-	3,840	-24,170	11,865
Recommended Practice (T3)		-	-28,010	7,845
Tilemsi PR Annual (T4)			-	36,035
Tilemsi PR Basal: one-time (T5)				-
Tinfouga (Cotton-Maize)				
Absolute Control(Tl)	-	319,025	224,560	278,935
Recommended Practice (T3)		-	-94,465	-40,090
Tilemsi PR Annual (T4)			-	54,375
Tilemsi PR Basal: one-time (T5)				-

[a] All figures are rounded to the nearest 5FCFA.
[b] 50OFCFA=$1.00 after January 1994, prior to January 1994: 25OFCFA=$1.00.

ers and the mixture is pressed into a granular product. The potential future role of Tilemsi PR is in direct application as a soil amendment and in replacing the P source of compound fertilizers. Costs considerations, however, have to be addressed including the potential environmental benefits.

Conclusion

The deficiency in P in most West African soils must be addressed in any strategy to increase crop production in the region. Indigenous phosphate rocks suitable for direct application have been identified in previous studies. The results of this farm-level evaluation of the Tilemsi phosphate rock under farmers' conditions through farmer-managed trials clearly indicated that crop yields using TPR are of comparable magnitude to those of recommended cotton or cereal complex imported fertilizers.

The financial data shown in this paper strongly suggest that direct application of TPR is relatively as profitable as the recommended imported fertilizers. At two of the three sites where the study was conducted the financial benefit of direct application of Tilemsi PR is higher than for the recommended fertilizer practice. These results are in agreement with Kagbo [7].

Table 8. Net gains (FCFA ha^{-1} $year^{-1}$) over the absolute control for different management strategies in Mali

Site/Cop[d] strategy[b]	Management	Treatment Recommended practice[a]	Tilemsi PR annual	Tilemsi PR basal
Sougoumba/Cotton	L	-13,310[c]	-19,790	-5,565
	M	13,975	12,510	17,500
	H	37,435	40,135	37,305
Sougoumba/Sorghum	L	-5,205	-14,220	-20,970
	M	2,865	2,295	3,585
	H	6,235	9,085	13,690
Tafla/Groundnut	L	4,525	3,240	6.320
	M	3,245	2,680	2,400
	H	845	1,640	-5,360
Tafla/Millet	L	665	20,585	18,220
	M	7,565	7,015	10,135
	H	11,105	6,495	1,049
Tinfouga/Cotton	L	44,575	-35,260	-45,645
	M	100,845	2,735	65,270
	H	122,775	39,625	89,750
Tinfouga/Maize	L	39,740	-2,235	-8,235
	M	91090	8,160	25,625
	H	119,995	71,105	66,780

[a] All figures are rounded to the nearest SFCFA.
[b] L=Low; M=Medium;H=High. Low management denotes that management practices are poor such late planting, very high density, late weeding, etc.; Medium management is an intermediate situation denoting an improvement over low management. High management signifies that the farmer is following the recommended cropping practices.
[c] A negative sign denotes that the strategy is dominated by the absolute control treatment.
[d] Cotton, sorghum, groundnut, millet and maize are evaluated at farm gate prices of 85FCFA kg^{-1}, 43FCFA kg^{-1}, 59FCFA kg^{-1} and 3BFCFA kg^{-1}, respectively.

The results also show that good management practices enhance the profitability of fertilizers in general.

At this stage it is strongly suggested that future research should include the assessment and documentation of the technical and economical feasibility of small-scale production of compacted fertilizers in Mali using TPR; the evaluation of the compact products in farmer-managed trials; and the targeting of relevant information to farmers, extension services, entrepreneurs and Government.

Acknowledgements

The authors acknowledge the very useful comments and suggestions of three anonymous referees. Financial support for this research was provided by the International Development Research Centre (IDRC), Canada and The Rockefeller Foundation.

References

1. Baanante CA & Henao J (1990) The economics of using indigenous agrominerals on maize-based cropping systems in

Mali. Paper presented at the second workshop on West African agrominerals, February 27 March 1, 1990, Lomé, Togo
2. Bouyer S (1954) L'emploi des phosphates naturels de Thiès dans l'agriculture sénégalaises. CR 2nd Conf. InterAfr des sols, Leopoldville. 1935 p
3. CIMMYT (1988) From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. CIMMYT, Mexico, DF
4. Diamond RB (1979) Views on marketing of phosphate rock for direct application. In: Seminar on phosphate rock for direct application, IFDC-SP-1, pp 448–463. International Fertilizer Development Center, Muscle Shoals, Albama
5. Goldsworthy PR (1967a) Responses of cereals of fertilizers in Northern Nigeria I. Sorghum. Exp Agric. 3: 29–40
6. Goldsworthy PR (1967b) Responses of cereals of fertilizers in Northern Nigeria II. Maize. Exp Agric 3: 263–268
7. Kagbo RB A comparison of natural phosphate Rock with Imported Cotton Fertilizer in Cotton/Cereal Rotation in Mali. Exp Agric 27:263–268
8. Khasawneh FE & Doll EC (1978) The use of phosphate rock for direct application. Adv Agron 30: 159–206
9. McClellan GH & Notholt A (1986) Phosphate deposits of tropical sub-saharan African. In: Mokwunye A & Vlek PLG (eds) Management of Nitrogen Phosphorus Fertilizers in Sub-Saharan Africa, pp 1973–224. Marinus Nijhoff publishers, Den Haag
10. Mokwunye AU (1979) Phosphorus fertilizers in Nigeria Savannah soils. II. Evaluation of three phosphate sources applied to maize at Samaru. Trop Agric 56: 65–68
11. Pieri C (1971) Bilan des recherches sur la fumure phosphatée du Mali. CR Coll. fertilité des sols tropicaux, Tananarive, T1, pp 1139–1148
12. Pieri C (1971) Le point sur les essais de fertilisation des céréales de culture séches réalisées au Mali de 1954 à 1990. Doc. Roneo IRAT Mali. Section d'Etude des sols. 50 p
13. Poulain JF (1976) Amélioration de la fertilité sols agricoles du Mali. Bilan de treize années de travaux (1967-1974). Agron Trop 31(4): 403–416
14. Pichot J & Roche P (1972) Le phosphate dans les sols tropicaux. Agron Trop 27: 939–965
15. International Fertilizer Development Center (1989) Final summary report to IDRC IFDC/West Africa. IDRC phase 1-3-P-80-001, IDRC phase II-3-P-83-0282
16. International Fertilizer Development Center (1991) Progress Report to IDRC. On-Farm Fertilizer Evaluation and Adoption Project. IFDC/West Africa.
17. Jones MJ (1973) A review of the use of rock phosphate as fertilizer in Francophone West Africa. Samaru Misc. Paper 43. Institute for Agricultural Research, PMB, 1044 Zaria
18. Traoré F (1974) Etude de la fumure azotée intensive des céréales et du rôle spécifique de la matière organique dans la fertilité des sols du Mali. Agron Trop 29: 567–586
19. Thibaut F, Traoré MFC & Pichot J (1980) L'utilisation agricole des phosphates naturels de Tilemsi (Mali). Synthèse des résultats de la recherche agronomique sur les cultures vivrières et oléagineuses. Agron Trop 35: 240–249
20. Truong B, Pichot J & Bernard P (1978) Caractérisation et comparaison des phosphates naturels tricalciques d'Afrique de l'Ouest en vue de leur utilisation directe en agriculture. Agron Trop 33: 136–145
21. Yenny F (1973) Expérimentation agronomique avec les phosphates naturels de Tilemsi (Mali) en conditions de culture séche. Agron Trop 28: 1970–1978
22. Sanogo S, Gaborel A & Traoré B (1978) Etude des phosphates naturels de Tilemsi en zone cotonniére. Synthése des travaux de recherche. Doc. Roneo IER-DRA Section des recherches cotonniéres. 36 p.