

Chapter 10

Economic factors in the adoption and utilization of phosphate rocks

Increased population pressure, reduced length of fallow, deforestation and improper agricultural practices have led to widespread soil degradation in many parts of the developing world. An important manifestation of this environmental damage is the inadequate replenishment of soil nutrients and organic matter. In particular, phosphorus (P) deficiency is becoming critical in many soils. Moreover, because of complementarities in the uptake of plant nutrients, this deficiency threatens to disturb the viability of applying other nutrients. In order to preserve the sustainability of agriculture and safeguard the livelihood of large segments of the rural population, there is an urgent need to rebuild soil fertility and so maintain and improve current levels of productivity and farm income (Heerink *et al.*, 2001).

Sustainable intensification and shifts towards higher-value crops require a careful application of external inputs such as inorganic fertilizers. A number of factors have constrained fertilizer use, especially in sub-Saharan Africa and low-income Asia. The most important of these factors are: the limited financial means and risk-taking capacity of farmers; poor and expensive distribution systems for fertilizers (and marketable crop surpluses); a lack of adequate knowledge of the potential of using local phosphate rock (PR); and the absence of non-industrial techniques to increase the solubility of PR (Appleton, 2001).

In many countries, foreign-exchange shortages have constrained fertilizer use by restricting imports. Moreover, domestic supply has suffered from government interventions and regulations that have hampered the emergence of a private fertilizer trade. As a result, these countries have become excessively dependent on fertilizer aid. As most bilateral donors are reluctant to make long-term commitments for fertilizer aid, dependence on aid introduces a high degree of uncertainty and prevents the development of efficient input-supply and marketing systems. It also discourages fertilizer use because farmers do not feel secure in adopting fertilizer-intensive cropping practices when access to fertilizer is uncertain. Another disadvantage of fertilizer aid is that cheap, subsidized fertilizer aid reduces incentives to develop domestic resources, especially PR for direct application.

Following the implementation of structural adjustment programmes, the real price of imported fertilizer increased substantially, creating a further constraint on its use. However, at the same time, more expensive imported fertilizer is an incentive to develop domestic substitutes. Coupled with a generalized donor fatigue with project and commodity aid, the restoration of soil fertility through programme aid is being considered increasingly as a lasting and more cost-effective substitute for food aid. Through higher yields, improved soil fertility constitutes a long-term contribution to enhanced food security.

Expenditure on the application of P sources, especially those with a significant content of less soluble P such as PR, can be considered as a restoration of the natural resource base. This is because it augments and maintains the stock of natural capital embodied in soil resources.

In this respect, PR is to be seen as an amendment that improves the soil, making the use of current inputs such as fertilizer for crop uptake, water and labour more efficient. Both farmers and society benefit from increasing agricultural output and decreasing nutrient depletion in agricultural production (Gerner and Baanante 1995). Defined in this way, PR application can be considered a capital investment.

The distinction between PR application as a soil amendment and as a crop fertilizer is an important one. Phosphate fertilizer can be produced through relatively simple PR beneficiation as well as through further industrial processing. PR and water-soluble phosphates, such as single superphosphate (SSP), triple superphosphate (TSP) and di-ammonium phosphate (DAP), are then competing inputs that farmers will select on the basis of price, availability, quality and other characteristics. The relevant question is under which circumstances PR based on domestic resources has a competitive edge over industrial fertilizers. Moreover, farmers can combine PR as a basal soil amendment with regular applications of industrial fertilizers.

PR as a capital investment raises various issues regarding the financing of such soil amendments. First, investment is lumpy, requiring an initial investment of large doses of PR that yields returns over a long period of time. Resource-poor farmers often do not have adequate financial resources to invest, nor are commercial banks willing to lend because of the high risk and poor collateral. Second, it rebuilds the natural fertility of depleted soils. Investment in soils is comparable to land reclamation or land improvement projects. They all require public investment, which enhances private profitability on a long-term basis and changes comparative advantages in production.

POSSIBLE ADOPTION AND USE OF PHOSPHATE ROCK BY END USERS

Case studies of PR application in Burkina Faso, Madagascar, Mali and Zimbabwe (World Bank, 1997; NEI, 1998; Kuyvenhoven *et al.*, 1998b; Henao and Baanante, 1999) show that farm-level rates of return can be highly attractive for various crops, and even more so when the environmental impacts on society at large are included. Despite these results, adoption in practice remains limited. In contrast with local PR, derived and usually imported phosphate fertilizers often perform better (Appleton, 2001). However, widespread use of such imported sources of P cannot be observed either, except for a number of commercial crops. A cost-benefit analysis of fertilizer application captures only part of farmers' adoption behaviour. In order to understand the factors that constrain adoption more fully, a more complete analysis of farm-household livelihood strategies is needed.

In general, farm households adopt those practices, technologies, enterprises and activities (agricultural and non-agricultural) that suit their objectives best given their own resource endowments, constraints and the socio-economic environment in which they operate. This implies that particular interventions such as PR application should not be analysed in isolation but considered in conjunction with competing options (in terms of time, labour, finance, income, etc.) for the farm household or firm. It is in this sense that profitability is only a necessary condition for adoption.

Major factors that have been found to determine adoption, and that of PR in particular, are: ownership and property rights (or continuous possession) in order to ensure access to income flows; farm size; share of land under cropping and stocking rate (indicators of resource pressure); access to credit; off-farm income available for on-farm investment; farming system; the prices of and the access to timely and adequate supplies of fertilizers and other variable inputs; and

knowledge of and access to information about the use of fertilizers and agricultural production technology in general. These factors influence the time horizon (and implicitly the discount rate) for investment decisions and the degree of relative risk aversion of the farm households involved.

Farmers often do not own the land they work. Therefore, they are often unwilling to invest in long-term land improvement. Farmers with well-established land access rights will obtain all of the short and long-term added revenues associated with PR application. Farmers who have usufruct of land on a long-term basis through land-leasing arrangements, such as sharecropping, will share these benefits with landowners who may be private landlords or with the community as a whole. Tenant farmers who are sharecroppers on the land for only one cropping season will not obtain any of the long-term benefits and only a part of the short-term benefits (Gerner and Baanante, 1995). The ownership/property rights land system in many of the least-developed countries (LDCs) can be characterized as a traditional communal type of land tenure and land use with the following characteristics: (i) low property concentration (sovereign rights vested in the community); (ii) decentralized cultivation (usufruct rights for group members); and (iii) production for subsistence. Hence, investment in PR is most likely to be implemented as a public action investment. Therefore, the community as a whole and not individual farmers should pay for it.

A capital investment in the soil by means of PR application has high up-front cost and yields returns over a long period of time. Access to credit is generally limited. However, off-farm income can help to overcome a capital constraint or may finance the purchase of a fixed-investment type of innovation (Feder *et al.*, 1985). Farm size can have different effects on the rate of adoption of new technologies, such as PR use, depending on the characteristics of the technology and institutional setting. The relationship between farm size and adoption depends on factors such as fixed adoption costs, risk preferences, human capital, credit constraints, labour requirements and tenure arrangements. An often-mentioned constraint on technology adoption by smaller farms relates to the fixed costs of implementation. In the case of PR application, these costs are of considerable importance. Large fixed costs reduce the tendency to adopt and slow the rate of adoption by smaller farms (Feder *et al.*, 1985).

Most farmers willing to invest in PR have a relatively intensive farming system. In such cropping systems, animal traction is already available and manure is applied. The PR to be applied to restore long-term fertility should also be available to farmers on time. This is because application after the optimal period reduces the possibility of immediate yield increases. Labour availability is another variable that affects farmers' decisions about adopting new agricultural practices or inputs. It is a particularly important factor in Africa (Helleiner, 1975). New technologies such as PR application increase the seasonal demand for labour. Hence, adoption is less attractive for farm households with limited family labour or those operating in areas with less access to labour markets. Labour shortages arise mainly as a result of male labour migration, the excessive burden on women and a lack of animal power. The consequences are late ploughing, late planting, late weeding, late harvesting and low yields.

A constraint that relates specifically to phosphatic fertilizer involves the time lag between application and visible effects. Depending on the reactivity of the PR, observable effects may occur during the cropping season of application or three or more years following application. Lack of education and extension services can be another constraint on PR use. The inability to read and understand fertilizer packages and instructions restricts the effectiveness of using written information as a means of disseminating knowledge about fertilizers. Field research experience has shown at least one unique constraint on the use of PR. In West Africa, farmers

complained that when broadcasting finely ground PR, windy conditions forced the product into their eyes and caused a burning sensation.

The factors mentioned here correspond well with those given by Henao and Baanante (1999) in their Mali case study. They emphasize the “magnitude and relative importance of the marketable surpluses of rural households from farming, e.g. outputs and prices of crop and animal production. Sustainable expansion of farmers’ marketable surpluses should be associated with expansion in the adoption of PR and other external inputs. The lack of marketable surplus associated with subsistence farming is a serious constraint to the adoption of PR and other external inputs. It is important to note that the sustainable growth of farmers’ marketable surplus also depends on the existence of market outlets and the demand for their products that can ensure stable and suitable prices” (Henao and Baanante, 1999). Appleton (2001) reported similar conclusions on farmers’ behaviour.

Enyong *et al.* (1999) examined farmers’ perceptions and attitudes towards introduced soil-fertility enhancing technologies (SFETs) in West Africa. They concluded that farmers are knowledgeable about and practise SFETs that encompass PR application, crop residue and farmyard manure, chemical fertilizer and crop rotation to combat soil fertility decline. A number of factors influence their attitudes to and rationales behind adoption decisions. These factors include land use policies, labour resources, food-security concerns, perceived profitability, contribution to sustainability and access to information. Enyong *et al.* (1999) observed that some of these factors are beyond farmers’ control and require a broad and integrated effort from research, extension and government to promote the use of the SFETs (including PR) in the region.

COST OF PRODUCTION, TRANSPORT AND DISTRIBUTION

Various countries in the developing world possess PR reserves, but few of these resources are exploited commercially on a substantial scale. Appleton (2001) provides a comprehensive survey on reserves, production and infrastructure conditions in sub-Saharan Africa, but warns that cost figures for PR production, transport and distribution vary widely, depending on site characteristics and available infrastructure. Each case is likely to be substantially different, precluding any general conclusion on the viability of mines and processing plants without a detailed technical, economic and institutional/organizational appraisal. Once such prefeasibility studies have justified further investigation, a full feasibility study can begin.

In view of the widely varying mining, production and distribution circumstances, this first section is confined to a brief overview. Subsequent sections provide some general information on the marketing of PR in various parts of the world, while the final sections present a case study on large-scale PR production in Venezuela to illustrate some characteristics of the production chain. The remainder of this section deals with aspects of PR production in sub-Saharan Africa.

Senegal and Togo produce PR, but the bulk of their phosphate is for the production of chemical fertilizer. Mali, Burkina Faso and Niger also have PR, but its exploitation is on a small scale. The quality is insufficient for use in the chemical industry. Moreover, transport costs are prohibitive. Several attempts have been made to promote large-scale utilization of PR, but success has been limited. One of the main reasons is the relatively high price of the product.

Equipment for grinding is rather heavy and investments are only profitable for large quantities. The equipment is technically simple and operational costs per tonne are relatively low. Enlarging the quantities would enable considerable economies of scale. While the existing

factory in Burkina Faso produces some 2 000 tonnes of PR per year at an ex-factory price of about US\$97.00/tonne, investment in a new factory to enlarge production to 30 000 tonnes/year would result in a price of less than US\$24.25/tonne. This is comparable with the ex-factory prices of PR in Togo and Senegal (NEI, 1998).

PR is a voluminous product. Its bulky nature, combined with the long distances from the mines to the fields and the often poor conditions of the roads, makes unit transport costs very high. Where the production costs of PR are considerably lower than those of chemical fertilizers, this cost advantage is partly offset by the higher transport costs. This is because of the lower effective P content of PR in comparison with water-soluble P fertilizer and, hence, the larger quantities needed to obtain the same results. The same is the case for PR of different origin. Locally produced PR is cheaper than imported PR, but the advantage quickly diminishes with geographical distance. Consequently, PR application will remain limited geographically, but within such areas it might be interesting.

Unlike chemical phosphates, PR is not a homogenous product. First, the P_2O_5 content differs. Senegalese and Togolese PR have a content of some 38 percent, Malinese PR from Tilemsi has a P_2O_5 content of 32 percent and Burkinese PR a P_2O_5 content of about 27 percent P_2O_5 . Another difference is the solubility. While TSP is water soluble, PR is water insoluble. In particular, the reactivity of Burkinese PR is relatively low. Consequently, more PR is needed in order to achieve the same fertilizer effect than a comparable quantity of TSP. On average, it is necessary to apply three to four times as much Senegalese PR compared with TSP and six times as much Burkinese PR in order to obtain the same fertilizing effect, at least in the short term. This is offset partly by the fact that the less soluble products have a more lasting effect, up to 7–10 years, but exact figures are not available. However, such a period exceeds the time horizon of most West African smallholders.

The differences in PR quality diminish the geographical area in which a certain PR product quality can be applied profitably. In Burkina Faso, unit prices of Burkinese PR are lower than those of imported PR. However, the importation of Senegalese PR might be more attractive in the southwest of the country once quality differences are taken into account. Nevertheless, local PR production remains promising for the central regions, where the need for soil-fertility conservation and restoration is highest.

Appleton (2001) summarizes these considerations: “Phosphate rock is a low value, high volume commodity with high transport costs, so the economic potential of a phosphate rock deposit will be determined to a large extent by its location in relation to domestic and international markets. Most commercial phosphate rock deposits are located close to the coast and in countries with efficient deep-water port facilities. If the transport infrastructure in a country is poorly developed and especially if railways or slurry pipelines are not available to transport the phosphate rock, it may be more cost-effective to import high-analysis fertilizers such as DAP, rather than to develop local resources. Phosphate rock resources sited in geographically remote and/or unfavourable locations at great distances from markets or from efficient transport facilities are unlikely to be economic to utilize for international markets, whereas local or perhaps regional use may be an economically viable option. Conversely, for agricultural areas located at a great distance from the coast, especially in landlocked countries, it may be more cost-effective to develop local phosphate rock resources for use as direct application fertilizer rather than to import manufactured fertilizers. High transport costs may be of less importance if the phosphate rock can be converted into a high value manufactured fertilizer product, although the quantity and quality of the phosphate rock resources may prevent this.”

ECONOMIC CONSIDERATIONS AND POLICIES TO SUPPORT PR ADOPTION

At the macro level, economic effects are usually measured through changes in private or public sector income, i.e. consumer and producer surplus, rent and government-budget effects. In addition to these efficiency-related goals, redistributive and environmental criteria are usually introduced. PR application generates extra employment in both mining and processing and in the infrastructure sector. Therefore, it can mitigate out-migration. These sectors need complementary investments by the government. For many governments, the aggregate impact on public finance (over and above direct project effects), employment, migration, and the balance of payments is an important consideration.

Intensification, new varieties, better fertilizers and reduced transport costs shift the agricultural supply curve to the right, causing output increases and/or price reductions. Welfare gains differ sharply when the good is a non-tradable (sorghum, millet) as opposed to a tradable (cotton) or a commodity subject to government price support. In the case of a non-tradable good, increased production results in decreases in price, and consumers are the main beneficiaries. With a tradable good, it is possible that no price change will occur. Therefore, farmers gain, resulting in increased land rents, while the gain to consumers is small or negligible. In the absence of a more comprehensive analysis, the following effects of PR application are of wider concern.

First, to the extent that PR investment affects food crops, it is likely to increase overall food security. With supporting services in place, higher average yields per hectare will raise total food availability, causing local prices to decrease under the closed-economy assumption. Such a development will alleviate at least in part the problem of access to food for the urban poor. In the event of a year with lower rainfall, the influence of PR on production will still be felt, and the lower output level is likely to exceed that in a normal year without the application of PR. Thus, sustained PR use can reduce output fluctuations and stabilize prices. To the extent that PR substitutes for imports of TSP, PR has a positive effect on the balance of payments. As the use of PR also raises agricultural production, food imports will not need to be so high.

Second, PR application is one of several ways of improving soil fertility improvement. It is a matter of cost-effectiveness as to which method is the preferred one in a particular location. The discussion about the best way to improve soil fertility should not distract attention from its role as a powerful instrument for triggering sustainable intensification, improved productivity and higher incomes. As Sissoko (1998) has shown, among 12 instruments for stimulating sustainable agriculture in Mali, "valorisation/bonification des terres" stands out as one of the most effective. Others are: output price support, lower transaction cost and fertilizer subsidies.

Third, more extensive analysis of policies to promote sustainable intensification in Mali (Kuyvenhoven *et al.*, 1998c) shows that making more sustainable production conditions available through research and extension enhances resource efficiency. However, without special incentives for adoption, adjustment costs may well outweigh marginal benefits. The impact of these policy incentives differs among farm types. Fertilizer subsidies encourage less soil-depleting technologies in cash crops (cotton), but at the expense of more soil-depleting cereal activities. In this sense, fertilizer subsidies are inefficient in terms of resource use and reduce local food surpluses. As a result, food prices will increase, and farmers will be stimulated to revert to less soil-depleting methods. However, the food security of the net buyers of food (urban households) will now decrease because of higher prices, causing a policy dilemma.

As the case studies illustrate (below), the environmental benefits of PR application can be considerable, justifying some form of public or donor support to foster higher and faster rates of adoption where this appears desirable. The economic considerations mentioned above enable

the identification of policy measures that may enhance farmer adoption of PR. A distinction will be made between price policies and institutional developments that contribute to creating a so-called ‘enabling environment’ for adoption, and extension programmes that support farmers’ knowledge and information on PR.

Pricing policy

Few LDCs have been able to implement and sustain crop and fertilizer pricing policies to create stability and conduciveness in the pricing environment and to provide incentives for the adoption of fertilizer using crop technologies. Price stability should be ensured in countries that choose to develop their PR resources. Price stability and profitability are necessary for the adoption of fertilizer use in general and P as a capital investment by farmers in particular. Incentive pricing is needed to encourage farmers to use adequate quantities of appropriate plant nutrients, thereby sustaining agricultural production through investment in soil-fertility maintenance. The pricing policy should be such that it maintains favourable cost-benefit ratios for farmers’ cropping activities compared with their off-farm activities (Teboh, 1995; World Bank, 1994).

In this context, two reasons can be advanced for considering fertilizer subsidies. First, only large-scale production can achieve economies of scale. At current prices, demand will never increase to levels necessary for realizing low production prices, while the latter do not decrease by lack of demand. Subsidies can break this vicious circle. Moreover, it allows the innovators to apply a new, politically and technically desired product at affordable prices. A subsidy that bridges the gap between the current prices and the lower price at large-scale production is relatively easy to manage. Furthermore, it disappears automatically when PR production increases. The second reason for subsidizing PR is the interest of the community in preserving the fertility of its soils, something that exceeds the individual interest of the farmer.

Organizational policy

Efficient and adequate organizational arrangements are essential for supplying fertilizers and other inputs on time, in the right type and quantity, and at the right price. Inefficiencies in creating adequate organizations have also constrained growth in fertilizer use in many African countries. In addition to fertilizer distribution, the distribution of PR as P capital imposes extra burdens on the marketing and distribution system because additional product tonnage has to be transported from the mining site to the consumption areas. Managing such large quantities requires organization at all levels, namely: mining, processing, transport, storage and marketing.

Agricultural product markets

Enhancing soil fertility is supposed to lead to higher production. For the individual farmer, this is the main rationale for applying PR. However, some or all of the additional produce needs to be marketed. In many countries, markets for agricultural products are fragmented. In West Africa, the cotton market is the best organized one in terms of marketing and distribution, including that of fertilizers. On the other hand, the application of modern technology and inputs for traditional cereals often remains limited as farmers are often unable to sell surplus production at reasonable prices. The promotion of PR in the interests of conserving and restoring soil fertility might require governmental measures in order to ensure an outlet for traditional farm products. However, the trap of reinstalling the old marketing hoards should be avoided. One solution could be to establish minimum prices well below normal market levels but to guarantee each

desired sale. If these marketing problems are not addressed, technological innovations will remain confined to promising cash crops such as cotton, rice, certain vegetables and products with an institutionalized demand for the agro-industry (e.g. peanuts).

Risk protection

Agriculture depends considerably on climate conditions. In particular, the risks of farming are high in arid and semi-arid zones. Many farmers are reluctant to invest in agriculture or to contract loans in the face of such uncertainty. Credit institutions are often hesitant about granting loans because they fear repayment problems. This hampers the introduction of those new technologies that require capital investments.

Some kind of risk insurance could help farmers and banks to mitigate this problem. While prohibitive costs exclude comprehensive coverage of income risk, limited insurance systems might be possible, e.g. rescheduling of payback conditions in the event of crop failure, and temporary payment of interest out of a special fund. Government interventions to support farmers and credit institutions might be desirable in order to maintain financing risks at acceptable levels.

Research and extension policy

Despite considerable research and attention directed to the issues of technological adoption, a consensus has not developed regarding the social and economic conditions that lead farmers to adopt new production practices. It is unclear why some farmers adopt new technologies and others do not. As shown by Rauniyar and Goode (1992), adoption of technological practices tends to be interrelated. Therefore, programmes should emphasize the technological adoption of packages of practices rather than individual practices or a package containing all practices.

Countries in areas such as the Sahel still lack the necessary research and extension facilities for promoting fertilizer use and associated technologies. Research is needed to develop site-specific fertilizer recommendations, including the use of PR amendments, and to enable extension services to educate farmers and producers on fertilizer use and improve services. Because PRs differ in their reactivity levels and crops differ in their P requirements (demand and pattern), it is necessary to identify appropriate PR application rates for different cropping patterns in various agroclimatic zones. Applied agricultural research and extension services should be equipped to perform their different roles effectively. In addition to facilitating farmer application of recommended, research-based agricultural practices, extension services should assist farmers in understanding the environmental damage associated with various farming practices. Specifically, the rural poor should be made aware of the full implications of using technology provided by outside institutions (Teboh, 1995; World Bank, 1994).

The market and infrastructure perspective conceptualizes the diffusion of innovations as a process involving three principal activities: (i) establishment of a diffusion agency to make the innovation available to the client system; (ii) selection and implementation of strategies that include pricing and promotional communication in order to induce adoption; and (iii) adoption of the innovation by the client system. This perspective is complementary to the traditional adoption perspective. Farmers' resource endowments and attitudes, as well as the socio-political and physical environments in which they carry out their daily activities, are potential determinants of their adoption behaviour.

In general, farmers adopt innovations most rapidly when: (i) the farmers perceive that the innovations have a relative advantage over the practices they supersede; (ii) the innovations are compatible or consistent with their own values; (iii) the innovations are easy to understand and use; (iv) the innovations are amenable for experimentation on a limited basis; and (v) the innovations are capable of producing visible results (Rogers, 1983).

CASE STUDIES OF PR EXPLOITATION AND USE

The International Fertilizer Development Center (IFDC) and the World Bank conducted various case studies of PR use in the second half of the 1990s following international initiatives. Table 30 presents a summary of findings for Burkina Faso, Madagascar and Zimbabwe from a study by the World Bank (1997). Table 31 present findings for Mali from a study by the IFDC, based on the same methodology (for different regions and crops) (Henao and Baanante, 1999). Both studies report substantial rates of return at the assumed PR cost, important environmental benefits, but also better results at the farm level if alternative sources of industrial P fertilizer are applied.

Constraints of the type discussed above are recognized as limiting potential demand. Their removal, together with a strong political commitment and a comprehensive approach to PR exploitation, would be necessary in order to make PR application a successful proposition.

In the IFDC Mali study, risk and credit constraints are emphasized as factors that reduce the incentive to apply fertilizer. Another Mali study based on World Bank data (Kuyvenhoven *et al.*, 1998a, 1998b) analyses the income position of farmers adopting PR with loan financing, under the assumption of limited rainfall that reduces yields by 50 percent every third year. Under such circumstances, farmers would be unable to meet their financial obligations in bad years, and would need refinancing of their loans. This factor would limit both farmers' willingness to apply PR or other alternatives and the willingness of financial institutions to extend credit.

In a study of Burkina Faso, Hien *et al.* (1997) found that farmers faced with risk may forego the higher returns of PR over commercial fertilizer and choose the latter, more soluble product. Only under a limited supply of commercial fertilizer would farmers prefer PR, especially of the partially acidulated type.

In a review of fertilizer use in semi-arid West Africa, Shapiro and Sanders (1998) concluded that under existing farming conditions "imported inorganic fertilizers are the only technically efficient and economically profitable way to overcome prevailing soil-fertility constraints and alternative soil-fertility measures, such as organic fertilizers and natural rock phosphate, should be seen as complements to rather than substitutes for imported inorganic fertilizers, until wider experimentation makes them more successful."

As most case studies illustrate, PR application appears interesting and beneficial as it improves soil quality and increases yields. However, a PR project would also encounter numerous problems. Many farmers in LDCs lack complementary inputs and, therefore, are not able to apply PR adequately. During peak season periods, labour is scarce. Applying PR would increase labour demand particularly during these periods. With labour in short supply, a situation might occur where the farmer would not be able to profit from the benefits of the PR application because of delayed planting/seeding or the inability to harvest the increased yields fully. Other problems arise with the application of PR. PR development is a lumpy investment. As farmers cannot obtain credit from a bank because of poor collateral, they cannot finance PR purchases easily. Another problem concerns the willingness of farmers to adopt PR application as a technique for improving soil fertility. Research has shown that fertilizer use in low-income

TABLE 30
Matrix of costs and benefits associated with PR investments

Description	Burkina Faso	Madagascar	Zimbabwe
PR reserves			
Quantity (million tonnes)	63.0	0.6	47.4
Type	Sedimentary	Guano	Igneous
Reactivity	Moderate	High	Low
Incremental cumulative yield (kg/ha)¹			
Maize	3 262	25 000	4 050
Sorghum	3 249		
Millet	1 801		
Paddy rice		5 020	
PR costs			
Ex-factory (US\$/tonne)	152.6	103.4	37.3
Farm level (US\$/ha)	78-110	92-372	35-45
PR benefits (NPV, US\$/ha)²			
<i>Private - total</i>	131-137	3 878-7 492	500-517
Yield effects	122-128	3 878-7 492	500-517
BNF	9	854-938	
<i>Environmental - total</i>	317		210
Prevention of land degradation	208		147
Carbon sequestration	99		
Prevention of phosphogyp. pollution	10		63
<i>Others (not quantified)</i>			
Food security	High	High	Medium
Forex. savings	Medium	High	Low
Intergeneration equity	High	Medium	Medium
Impact on women farmers	Positive	Unknown	Unknown
Prev. of soil erosion/sedimentation	Medium	Medium	Low
Preservation of biodiversity/forests	Low	High	Medium
Other adverse environmental impacts overall:			
Ecological damage	Minimal	Manageable	Minimal
Land reclamation cost (US\$/tonne)	Minimal	Moderate	Minimal
Eutrophication	Insignificant	2.2	1.0
	Minimal	Minimal	Minimal
Sharing of benefits (NPV, US\$/ha) (%)³			
Private/local	270 (46)	2 775 (43)	867 (81)
National	208 (35)	3 534 (55)	147 (14)
Global	109 (19)	129 (2)	63 (5)
Description	Burkina Faso	Madagascar	Zimbabwe
NPV of alternate products (US\$/ha)⁴			
<i>Private</i>			
Imported TSP	360		
DSP			1 302-1 313
<i>Environmental</i>			
Imported TSP	307		
DSP			216
Sensitivity analysis (NPV, US\$/ha)⁵			
Private benefits	90-219		381-731
Total benefits	482-725	8 561-6 750	906-1 299
Potential demand (tonnes) P₂O₅ (PR)/year	21 400 (79 300)	21 300 (106 500)	20 500 (58 600) ⁶
Constraints on PR investments			
Land tenure	Possible	Possible	Possible
Credit	Severe	Severe	Severe
Ecological (PR production)	None	Uncertain	None
Extension	Moderate	Moderate	Low
Competition from existing industry	None	None	High
Pricing environment	Unlikely	Unlikely	Unlikely
Conditions necessary for success			
Political commitment	Essential & available	Essential & available	Essential & unknown
Removal of constraints	Necessary	Necessary	Necessary
Investment in comp. packages	Essential	Essential	Essential

¹ From one-time basal application of PR.

² Private and environmental benefits are discounted by 10 and 3%, respectively.

³ Based on 3% discount rate.

⁴ Most profitable alternate product is included here.

⁵ Discount rates range between 5 and 15% for private benefits and between 1 and 5% for total benefits.

⁶ Phosphate rock concentrate.

Source: World Bank, 1997.

TABLE 31
Distribution of benefits for selected fertilizer strategies

Region	Cropping system	Fertilizer			Benefits*		
		Basal (kg/ha)	Annual	Private	Environmental (US\$/ha)	Total	Environmental %
Sikasso	MC	TPR:120		647.8	403.5	1 051.3	38.4
		TPR:120	TSP:15	1 021.3	403.5	1 414.9	28.5
	MM	TPR:120		325.6	344.2	669.8	51.4
		TPR:120	TSP:15	633.5	344.2	967.8	35.6
	CC	TPR:120		600.1	412.8	1 012.9	40.8
		TPR:120	TSP:15	1 200.3	412.8	1 603.2	25.7
Segou	MiG	TPR:120		605.7	351.0	956.7	36.7
		TPR:120	TSP:15	793.7	351.0	1 134.8	30.9
	MiMi	TPR:120		380.4	345.2	725.6	47.6
		TPR:120	TSP:15	599.8	345.2	925.1	37.3
	GMa	TPR:120		390.3	377.8	768.1	49.2
		TPR:120	TSP:15	672.9	377.8	1 040.8	36.3
GG	TPR:120		386.1	399.0	785.1	50.8	
	TPR:120	TSP:15	672.9	377.8	1 040.8	36.3	
	TPR:120	TSP:15	672.9	377.8	1 040.8	36.3	
Koulikoro	SG	TPR:120		788.6	370.9	1 159.5	32.0
		TPR:120	TSP:15	1 032.3	370.9	1 393.4	26.6
	SS	TPR:120		582.7	365.6	948.3	38.6
Mopti	Rice	TPR:120		836.9	433.0	1 269.9	34.1
		TPR:120	TSP:15	1 111.9	433.0	1 545.0	28.0
	Millet	TPR:120		311.8	356.2	667.9	53.3
		TPR:120	TSP:15	499.8	356.2	846.1	42.1

* Discount rate: private benefits = 10 percent; environmental benefits = 3 percent.
Source: Henao and Baanante, 1999.

countries is extremely limited. Most knowledge of soil-improving techniques for food crops has been disseminated by the farmers themselves rather than by extension workers. Finally, lack of infrastructure may prevent timely and adequate supply of the PR to the farmers, which is one of the necessary conditions for convincing them to adopt this technology.

Before a PR application investment project can be introduced successfully, other measures and activities are needed. These include: (i) addressing credit problems and land rights; (ii) improving and extending rural infrastructure; (iii) improving marketing and distribution networks; and (iv) increasing the effectiveness of extension services. The securing of land rights for farmers will increase their ability to apply for credit and their willingness to invest in their land. Rural infrastructure needs to be improved and expanded in order to guarantee the timely and adequate supply of PR to the farmers. An improved rural infrastructure will also have a favourable impact on the distribution of produce to urban areas. Both farmers and the urban poor will then profit from reduced transport costs. Effective contacts between farmers and extension workers need to be developed so that extension services can be delivered effectively.

MARKETING OF INDIGENOUS PHOSPHATE ROCKS FOR DIRECT APPLICATION

Several countries have imported large quantities of PR for direct application. In 2000, Malaysia imported 500 000 tonnes, Brazil 320 000 tonnes, New Zealand 130 000 tonnes, and Indonesia imported about 230 000 tonnes in 1998. In other countries, indigenous PRs have been milled and marketed for domestic use on a relatively small scale with mixed results. PR sales depend on the supply of and demand for PR, competition with the imported P fertilizers, government

policy, etc. The following sections provide information on the marketing of indigenous PRs in some countries where farmers have used PRs for crop production.

Latin America

In Colombia, there are several PR deposits. The only PR source being marketed for agronomic use is a medium-reactive Huila PR (product name: Fosforita Huila). In 1994, a company called Fosfacol sold 25 000 tonnes of Huila PR, about 15 percent of Colombia's annual consumption of P fertilizers. According to the company, sales are growing. However, no recent sales figures are available.

In Peru, there is a huge deposit of a highly reactive PR (Sechura or Bayovar). However, owing to various problems, there has been no large-scale milling of this deposit for marketing. Small quantities of Sechura PR are reportedly being marketed in the country and for export to Chile for direct application.

In Chile, the highly reactive Bahia Inglesa PR has been marketed for pastures and crop rotations in the volcanic-ash-derived soils in the south of the country. A company called Bifox markets the product under the name Fosfato Natural Chileno. Over the past 10 years, the average annual PR consumption has reportedly been about 10 000 tonnes of Fosfato Natural Chileno.

In Brazil, attempts to use the numerous PR deposits for direct application yielded poor agronomic results because of the low reactivity of the PRs, and direct application was discontinued. Some local PR sources are used to produce thermophosphates by fusion of mixtures of PR and basic slags at high temperatures.

In Venezuela, existing PR resources are not very reactive, except for one PR. A company called Pequiven is using this Riecito PR to produce commercial-grade PAPR products. The company markets the products under the name Fosfopoder and sells up to 150 000 tonnes/year.

Asia

In India, several PR deposits have been mined on a large scale for use in the chemical acidulation process. In the early 1980s, a company called Phosphate, Pyrite and Chemicals Ltd. began to promote a low-reactive Mussoorie PR (product name: Mussoorie Phos) for direct application. In 1993–94, sales of Mussoorie PR for agronomic use were about 107 000 tonnes. However, the supply of Mussoorie PR is reportedly declining because of a limited PR reserve and a new government policy to curtail PR mining. A company called Rajasthan State Mines and Minerals Ltd. has marketed a low-reactive Jhamarkotra PR (product name: Raji Phos) for plantation crops in acid soils in coastal areas of the southwest region.

In Sri Lanka, mining of a low-reactive Eppawala PR commenced in 1974 with a production level of 3 000–5 000 tonnes. At that time, the country was importing about 50 000 tonnes/year of PR for direct application. Since 1992, a company called Lanka Phosphate Ltd. has increased the production of Eppawala PR steadily to 32 000 tonnes/year while PR imports have decreased to 8 000 tonnes. In 1998, Eppawala PR consumption amounted to 13 000 tonnes of P_2O_5 , representing about 43 percent of total P_2O_5 use in the country. Eppawala PR is used mainly for plantation crops, e.g. tea, mature rubber and coconut.

Sub-Saharan Africa

In terms of nutrients, P has been a major limiting factor on crop production in sub-Saharan Africa. The lack of a developed domestic P fertilizer industry and the limited availability of foreign exchange for fertilizer imports have prevented the resource-poor farmers from using expensive fertilizers. The average use of P fertilizers in sub-Saharan Africa is about 1.5 kg of P_2O_5 per hectare (in Asia and Latin America, the average figures are 34 and 20 kg of P_2O_5 per hectare, respectively). Numerous studies have attempted to determine whether indigenous PR deposits in sub-Saharan Africa can serve as sources of P in order to improve soil fertility and crop production.

In Mali, a medium-reactive Tilemsi Valley PR has been found suitable for direct application to acid soils for cotton, maize, rice, millet and sorghum. The entire production of PR is used within the country. The estimated production of ground PR was 4 529 tonnes in 1981, 8 092 tonnes in 1988, 11 000 tonnes in 1989, and 18 560 tonnes in 1990. Between 1991 and 1994, the production plant was often closed as a result of political unrest in the mine area. The estimated production potential is 36 000 tonnes/year.

In Burkina Faso, low-to-medium-reactive Kodjari PR has been mined on a small scale (about 1 000 tonnes/year on average). In 1993-94, PR production for direct application was reportedly 2 200 tonnes. The ground PR was promoted for a variety of crops including maize, rice and sugar cane. The estimated potential production capacity of Kodjari PR is 3 600–10 000 tonnes/year.

In Nigeria, a large reserve of PR of low-to-medium reactivity has been discovered recently in Sokoto State in the north of the country. Recent studies have shown that the agronomic effectiveness of Sokoto PR in terms of SSP was 40 percent on Alfisols, 100 percent on Ultisols, and 160 percent on Oxisols. The results of the field trials indicated that in the first, second and third years of cropping the agronomic effectiveness of Sokoto PR (in terms of SSP) was 54, 83 and 107 percent, respectively. A recently developed P product (product name: Crystal Super), produced by mixing Sokoto PR and natural talc magnesite ore, has reportedly been marketed by a company called Crystal Talc Nigeria, Ltd., in Kaduna. The company markets about 5 000 tonnes/year of this fertilizer.

In the United Republic of Tanzania, a highly reactive Minjingu PR deposit was developed in 1983. Production was about 20 000 tonnes/year (for acidulation) until the plant closed in the early 1990s. Of a recorded production of 2 500 tonnes in 1994, about 1 800–2 000 tonnes was exported to Kenya, where it was used for direct application and for SSP production, while 500–700 tonnes was sold for direct application in the north of the United Republic of Tanzania. The mine and processing plant now reportedly operate on a very limited basis.

Recently, the International Centre for Research in Agroforestry has reported promising results from agronomic trials on the use of Minjingu PR and a low-reactive Busumbu PR (Uganda) for different cropping systems, including agroforestry.

ECONOMIC CRITERIA IN PR ADOPTION AND USE – A CASE STUDY ON VENEZUELA

Venezuela plans to bring 46 percent more land under cultivation by 2018. The success of its efforts to expand the country's agro-industrial economy will depend on many factors. The most important of these factors relate to the large amounts of fertilizer required in order to achieve high agricultural productivity in tropical and subtropical areas with: (i) permanent crops, such

as sugar cane, coffee, cocoa, fruits, cassava, improved pastures and forestry, covering more than 6 million ha; and (ii) annual crops, such as maize, sorghum, rice, leguminous grains, oilseeds and cotton on more than 700 000 ha. The prices of traditional water-soluble phosphate fertilizers, such as SSP, TSP, NPK fertilizers, mono-ammonium phosphate (MAP) and DAP, are high.

About 70 percent of the agricultural soils of Venezuela are acid, with low-activity clays and high P-fixing capacity. This situation, together with large reserves of PR and the increase in the cost of imported P fertilizers, has promoted a diversification in the production of P fertilizers, especially in fertilizer produced from PR sources in the country (Casanova *et al.*, 1998). A more rational use of P fertilizers has been proposed in order to counter dependency on imported fertilizers (Casanova, 1993).

Agronomic evaluation and domestic market potential

TABLE 32
Partially acidulated phosphate rocks based on various Venezuelan deposits

Phosphate rock	Partially acidulated phosphate rocks	
	Concentration (% P ₂ O ₅)	Acidulation grade (%)
Riecito	25-33	40-60
Monte Fresco	25-34	15-40
Navay	20-24	40

The search for the most efficient ways of using the country's indigenous phosphate resources began with the sampling of three major existing PR deposits in Venezuela: Monte Fresco and Navay (Tachira State), and Riecito (Falcon State). A pilot plant produced PAPRs with H₂SO₄ and H₃PO₄ acids. Table 32 shows the main characteristics of the products.

Studies assessed the agronomic efficiency of the natural PRs and these PAPRs on various crops and soil types. The investigations focused on finding a process route for the production of low-cost phosphate fertilizers from the partial acidulation of indigenous PRs. Various national research institutes, universities, technical assistance companies and producers took part. International organizations, such as the IFDC (the United States of America), the Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD) and Technifert (France), CIAT (Colombia) and FAO/IAEA, provided additional assistance. The agronomic efficiencies of these PAPRs (20–30 percent P₂O₅ concentrations and acidulation grades of 40 percent and above) using conventional and isotopic techniques were assessed on various crops and soil types. They yielded excellent results in comparison with traditional fertilizers. Compared with the national average, yield increases of 29–100 percent were obtained in sorghum, maize, sugar cane, soybean and pasture (Casanova, 1998; Casanova *et al.*, 1998).

The results of the above evaluations, some of which spanned a period of more than 10 years, led to the following conclusions: (i) agronomic yields and efficiencies comparable to those with TSP were achieved by using PAPRs with 20–30 percent P₂O₅ concentrations and acidulation grades of 40 percent and above on annual crops such as sorghum, soybean, maize and permanent crops such as pasture and coffee; and (ii) a medium-term forecast of the potential domestic market for PAPRs of some 490 000 tonnes/year.

Economics of PAPR production

The next step was to establish the most economic route to convert PAPR profitably. The following factors were taken into account: (i) PR extractable and economically viable deposits, mining

infrastructure and capacity of installed production; and (ii) PAPR production process (process method, other raw materials, existing process synergy and product quality).

PR source

PR from the Riecito deposit proved to be the most attractive option as the deposit was already under commercial extraction by a company called Pequiven. There are both sufficient reserves and sufficient installed production capacity at the Riecito mine to support a production project that could satisfy the estimated potential market for PAPR in Venezuela.

The production capacity for the initial project was set at 150 000 tonnes/year of PAPR, equivalent to one-third of the estimated potential domestic market for PAPR. The Riecito deposit can satisfy more than 20 years of PAPR production at this capacity, in addition to meeting the rock feedstock requirements of other phosphate production plants (DAP and NPKs) at the Moron Complex. Table 33 shows the current installed P_2O_5 capacity at the complex.

TABLE 33
Current production capacity for P_2O_5 at the Moron Complex

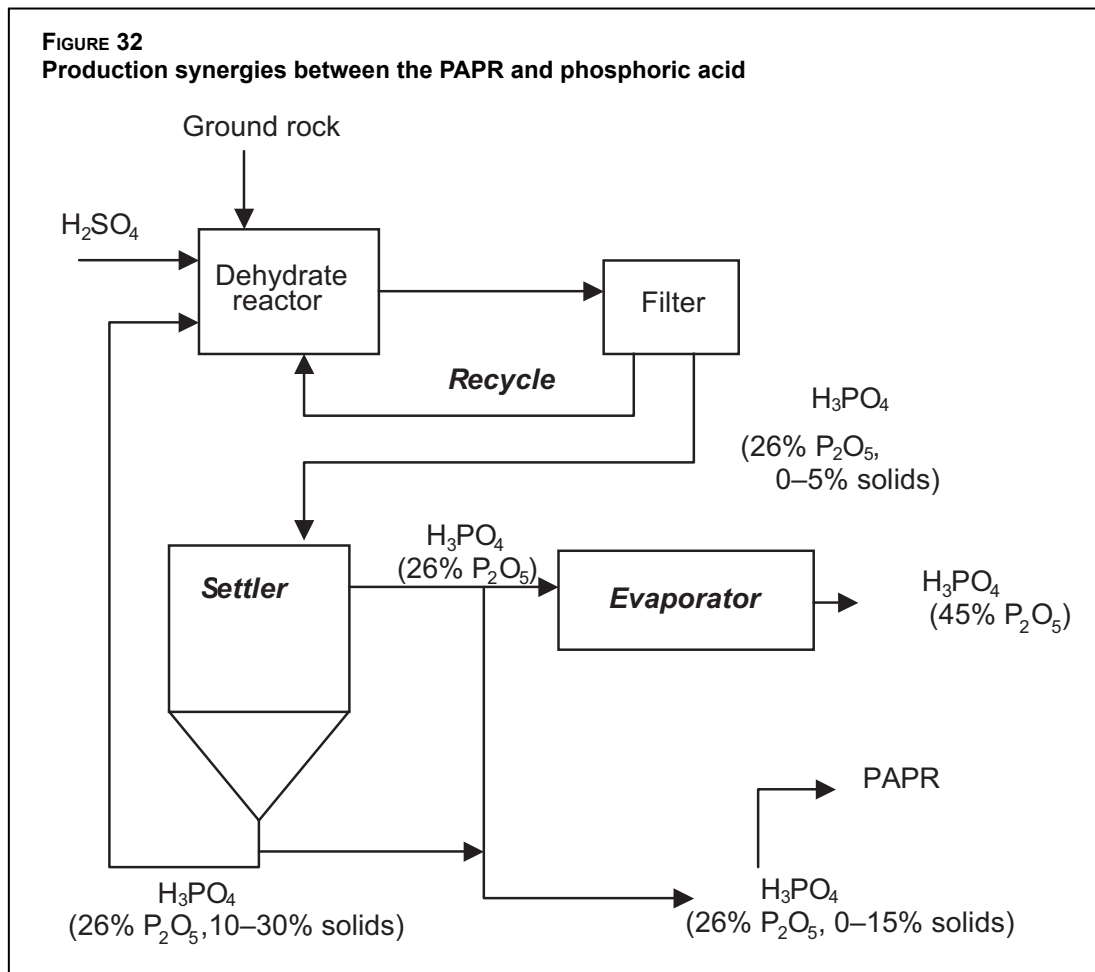
Product	Tonnes/year	P_2O_5 (tonnes/year)
PAPR	150 000	37 500
H_3PO_4	200 000	90 000
Total	350 000	127 500

Production process

From the process point of view, it is possible to produce PAPR commercially in several ways along the same lines as SSP and TSP. The preferred process should be one that gives the highest possible return on investment. With this aim in mind, the following factors were taken into account: the quality of the Riecito PR, process simplicity, integration with existing facilities, and the availability of other raw materials and services.

PR quality was a very important factor in deciding which process route to use. Based on the expertise accumulated over seven years of assessment of Riecito PR (acidulation, digestion, granulation, etc.) at the Petroleos de Venezuela Research and Technological Support Centre and a survey of the available technologies, it was determined that the most attractive process for Pequiven's specific conditions should have the specific technical features. These features are: (i) it should have the facilities for combined acidulation with sulphuric and phosphoric acids in order to provide the flexibility to produce PAPR ranging from 20 to 30 percent P_2O_5 ; (ii) it should be capable of using diluted H_3PO_4 with a wide range of solids content (26 percent P_2O_5 and 0–30 percent solids) in order to allow efficient use of clarifier underflow from the Moron phosphoric acid plant; and (iii) it should perform the two operations of acidulation and granulation of the PAPR in a single stage for the sake of process simplicity.

The chosen process for the Moron PAPR plant is based on the one-step PR-sulphuric acidulation method developed by the IFDC (Schultz, 1986). However, with the accumulated expertise of the Petroleos de Venezuela Research and Technological Support Centre on Riecito PR acidulation, it was possible to simplify the process by removing the cooling stage for the PAPR product. Figure 32 shows how the acid for PAPR production is taken from the phosphoric acid plant. The PR digestion stage in the dehydrate reactor has been optimized for the reduced solids content of the phosphoric acid recycled to the reactor, resulting from the withdrawal of



the filter-strength acid and clarifier bottoms for PAPR prior to entering the evaporation stage. It is estimated that this increase may represent up to 10 percent of the production capacity in the phosphoric plant. This has a significant impact on the economics of phosphate fertilizer production (DAP, NPK, PAPR) at the Moron Complex and augurs well for the profitability of the investment in PAPR production at the site.

Pilot-plant evaluation test

A pilot plant (500 kg/h of PAPR) evaluation was set up to test the proposed production process at the IFDC's facilities in the United States of America (IFDC, 1996). The evaluation results confirmed the feasibility of producing PAPR via the one-step acidulation/granulation process, using a combination of acidulants including H₂SO₄, H₃PO₄ and diluted H₃PO₄ with a wide range of solids content (26 percent P₂O₅, 0–30 percent solids). It also confirmed that the use of a product cooler was not necessary, as the resulting Riecito PAPR had excellent physical properties. Table 34 provides a summary of the results obtained during the pilot-plant assessment. These results helped develop the design basis for a commercial plant of 150 000 tonnes/year of PAPR at the Moron Complex.

TABLE 34
Pilot-plant evaluation results

Item	Results	Comments
One-step granulation/acidulation process	Feasible	Steady process
Combined use: H_3PO_4 (26% P_2O_5 , 0-30% solids) & H_2SO_4 (90-98%)	Feasible	
Granulation efficiency	> 90%	
Acidulation grade	40-60%	Predictable/calculable
PAPR concentration (% P_2O_5)	25-30%	Calculable
Product quality		
CRH (at 30 °C)	85-90%	High (excellent) CRH
Hardness	> 4 kg	Typical fertilizer > 2 kg
Impact resistant	< 1.5%	Typical MAP/DAP < 1.5%
Abrasion resistant	< 1.5%	Typical MAP/DAP < 2%
Hygroscopicity (at 30 °C) (mg/cm ³)	< 60	No hygroscopic typical fertilizer < 150

PAPR quality

Taking into account the agronomic assessment of various PAPRs (from Riecito and other sources) and the desirability of having a PAPR with a P_2O_5 grade close to the average P_2O_5 grade of the Riecito PR *in situ*, it was decided that the PAPR produced at the Moron Complex should have a P_2O_5 concentration of 25 percent and an acidulation grade of 50 percent. However, it was also considered desirable that the plant should have the flexibility to produce PAPR in the range of 20–30 percent P_2O_5 concentration and an acidulation grade of 40–60 percent.

In order to establish and forecast the required proportions of sulphuric acid, phosphoric acid and PR that may be necessary to produce a certain PAPR quality (P_2O_5 content, acidulation grade), a calculation programme was developed based on the reaction stoichiometry of Riecito PR in combined acidulation. The programme predicts the optimum relationship between the acidifiers needed and enables the process conditions and the associated variable costs to be established.

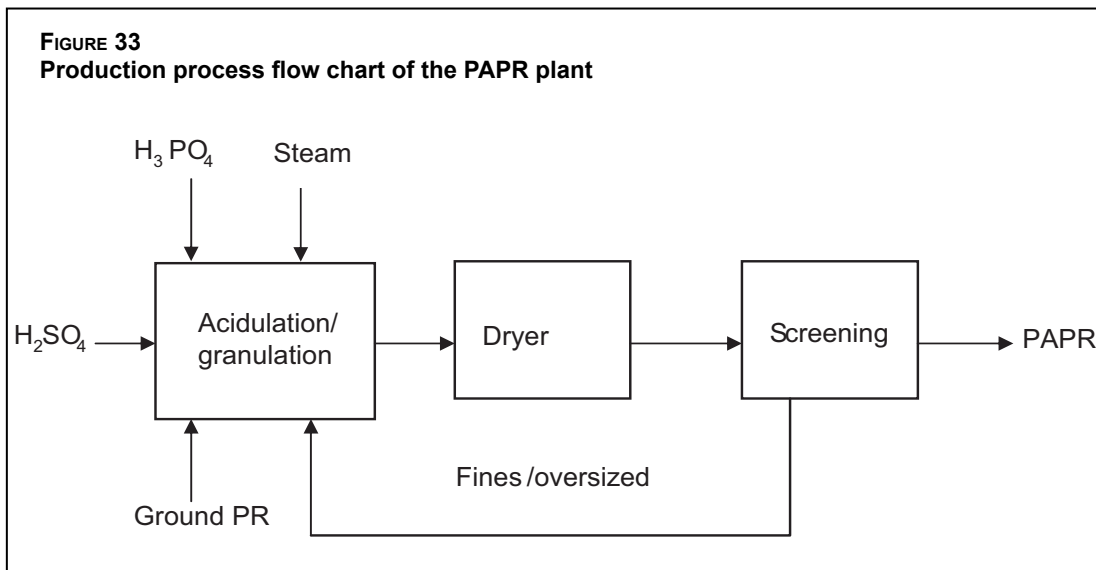
The Moron PAPR plant

The design project for the PAPR plant commenced in 1995, with the detailed engineering, equipment procurement and construction stage beginning in 1997. The production capacity of 150 000 tonnes/year (19 tonnes/h, on a basis of 24 h/day with a service factor of 330 d/year) determined the process equipment sizes. Since the completion of the installation guarantee test in November 1998, the PAPR produced has achieved both the physical and chemical quality standards required. The PAPR fertilizer is marketed in Venezuela under the name Fosfopoder.

Figure 33 shows the process flow chart with the six sections that make up the plant. The PAPR plant has a distributed control system (whereby the plants receives automatic information). The operation panels of this system are located in the phosphate control area, as are all the Moron Complex's operation control functions (Dominguez and Barreiro, 1998).

Raw materials and products

The PAPR plant at Moron has the flexibility to use a wide range of concentrations of raw materials. The expertise of the operations staff and the calculation programme installed in the control panel enable the product quality and production to be adjusted (Castillo *et al.*, 1998).



The calculation programme is based on the chemical equations and the material balance for the acidulation of Riecito PR with sulphuric and phosphoric acid and the heat transfer equations occurring in the process. In this way, it is possible to estimate the theoretical proportions of raw materials to product. The quality of the PAPR produced (grade, and acidulation percentage) has validated these calculations.

With regard to product quality, the use of 40–60-percent acidulated PR can achieve a PAPR quality with chemical specifications and physical qualities similar to other PAPRs with an acidulation of 40–60 percent.

In 1999, the first full year of operations, sales to the domestic market were about 15 000 tonnes of PAPR (10 percent of plant capacity). This can be considered something of a success given that PAPR is a new product for the Venezuelan market. In the near future, the plant will focus on the production of 25-percent P_2O_5 and 50-percent acidulation PAPR. The production is marketed under the generic brand name of Fosfopoder.