A REPORT FOR OPTIMAL USE OF EPPAWALA ROCK PHOSPHATE IN SRI LANKAN AGRICULTURE

Submitted to

The Hon'ble Minister
of
Science & Technology

NSF Committee on Eppawala Phosphate

National Science Foundation

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NSF Committee on Eppawela Phosphate

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Recommendations

In the development of the phosphate deposit at Eppawala, it is necessary to employ strategies that will yield maximum benefits to the national economy in the broadest sense. These include rapid and thorough survey of the deposit, mining according to a carefully drawn out plan, providing rock phosphate to meet domestic requirements and manufacture of more soluble fertilizer for short-term crops. It is necessary to pay careful attention to environmental aspects during all operations according to the Environmental Laws of the country. The deposit should be utilized so that the present as well as many more future generations could benefit from it.

After careful consideration of all the relevant factors and the scientific information available on this deposit, we would like to make the following recommendations regarding the development of this deposit.

1) Complete and comprehensive geological/geochemical study should be undertaken by the Geological Survey And Mines Bureau immediately to establish the total extent and the quality of the surface and subsurface parts of the deposit (northern and southern sections) at Eppawala.

2) Mining of rock phosphate should be done at a controlled rate (e.g. 350,000 mt per year) so that the present deposit could be utilized by several generations. However, if more deposits are found, the rate of exploitation could be revised, the guideline being that the ore should last at least 200 years for use in Sri Lanka's Agriculture.

3) Most feasible P-fertilizer products for use in Sri Lanka for local agriculture would be:

   a. Single Super Phosphate (SSP) and
   b. Partially Acidulated Phosphate Rock (PAPR)

4) Environmental safeguards must be strictly enforced according to the Environmental Laws of the country.

5) It is recommended to call for fresh worldwide tenders inviting proposals to set-up a phosphate fertilizer factory using Eppawala rock phosphate deposit stating the following guidelines/conditions among others if any:

The rate of exploitation (mining) should be about 350,000 mt of rock phosphate per year. Products should include SSP and PAPR.

Eppawala Rock Phosphate (ERP) should continue to be utilized for direct application (after beneficiation if necessary) for perennials such as tea, rubber and coconut.

EXECUTIVE SUMMARY

1. The mining of the Eppawala Rock Phosphate deposit should be viewed against the total phosphate resources of the world and their rate of exhaustion, environmental damage that mining can cause, social disturbances, destruction of national heritage sites and monuments; its exploitation and methods used to exploit it must at all times serve the greater national interest.

2. Herring and Fantel of the US Geological Survey and US Bureau of Mines, respectively, have shown **that the world's known reserves will be depleted in 50 years and the base reserves including the reserves will be exhausted in 150 years. Exploitation of uneconomic resources will need further development or advances in technology.**

   (Definitions used by Herring and Fantel on Resources and Reserves: " For our study, resources refers to known or indicated certainty of the existence of phosphatic material, regardless of grade, tonnage, or mining conditions. Reserves and reserve base, on the other hand, refer to those resources that could be economically extracted or produced at the time of assessment, or to that portion of the resources that meets certain minimum economic criteria related to current mining and production practices, respectively.

   The U.S. Bureau of Mines has defined reserves as the phosphate rock that can be mined profitably at present for less than $40 per ton (1992 dollars),.including capital, operating expenses, taxes, royalties, miscellaneous costs, and a 15 percent rate of return on investment, whereas reserve base (which includes reserves) is the phosphate rock that can be mined for less than $100 per ton with the same cost considerations as for reserves.............)"

3. A proposal from a U.S. mining company will exhaust the presently known reserves of Eppawala Rock Phosphate (ERP) in 30 years with insignificant economic benefit to the country.

4. We recommend that a rate of exploitation to meet the national needs only be adopted in the exploitation of ERP. At this rate of mining, the resource should last at least for 200 years.

5. We recommend the production of Single Super Phosphate (SSP) and Partially Acidulated Phosphate Rock (PAPR) as the fertilizers of choice for the country that can replace the imported Triple Super Phosphate (TSP).

6. The Single Super Phosphate is to be produced by a simple process that is environment-friendly. The production of SSP is highly advantageous to the country and the farmers.

7. The proposal from the U.S. mining company is highly, environmentally damaging and does not serve the national interest in any manner. The financial benefits largely accrue only to the foreign mining company.

8. Currently 50,000 mt of rock phosphate is produced from the Eppawala deposit mainly for use as a direct application fertilizer in the plantation sector – tea, rubber and coconut. If,

what the U.S. mining company proposes is implemented, the Eppawala Rock Phosphate reserves will be exhausted in 30 years. Thus Phosphate fertilizer, needed even for long term crops (of the plantation sector), will have to be imported at a very high cost. The cost per ton of ERP to the U.S. mining company is only 5 US dollars, while the current import price of Rock Phosphate per ton will be in the range of 75 US dollars.

9. The U.S. mining company proposal is not environment friendly – mountains of phospho-gypsum will accumulate polluting the environment.

10. **Exploitation of the Eppawala Phosphate deposit as proposed by the U.S. Mining Company may cause damage to Jaya Ganga, - a priceless engineering marvel that has stood the test of time.**

11. It should be mandatory to investigate the track record of any foreign company that would be given mining rights in Sri Lanka. Their record as regards pollution control measures and human rights violations need to be thoroughly examined.

INTRODUCTION

The Phosphate deposit at Eppawala in the Anuradhapura district was discovered and later mapped by Geological Survey in 1971. Its tonnage has been estimated at 40 millions of apatite rock. Initially it was stated that the deposit was of low-grade apatite and hence of less importance to agriculture. Subsequent works by Dahanayake and co-workers at the Institute of Fundamental Studies (IFS) have shown that the Eppawala Phosphate deposit has two components, high-grade relatively more soluble apatite crystals embedded in a matrix of lower quality apatite. They further stated that these two components could be easily segregated for processing. This research finding based on the studies done principally on the surface materials of the Eppawala Phosphate quarry has considerably changed the basis for any future commercial exploitation. Its implication for the processing of the unweathered underlying phosphate rock has to be carefully studied after a detailed geological survey of the deposit.

The Eppawala Rock Phosphate (ERP) is of considerable value to the country because Phosphate deposits are non-renewable and dwindling resources in the world like fossil fuel. Even if more phosphate deposits would be discovered in the world, its total quantity is finite and is exhaustible in the future. Studies estimating the total available deposits in the world and its life time assuming population growth rates, consumption of phosphate in agriculture, growth of income etc have been worked out in a landmark paper by Herring and Fantel of the US Geological Survey. This paper reported the demonstrated reserves at **12.0 Gt.** and the base reserves at **37.8 Gt.**_and their lifetime as 50 and 100 years respectively. Even if fresh deposits are found, it must be kept in mind that phosphate is an exhaustible and non-renewable resource. If very large resources of Phosphate are found elsewhere in the world at a later date, the government's position can be reviewed in the light of a further update to Herring and Fantel's study.

The policy decisions to exploit ERP must be taken in the light of existing internationally published scientific findings, and the recommendations of this study. As the world's phosphate reserves will be exhausted in 150 years, it is an inescapable conclusion that the deposit must be reserved for the country's use. ERP deposit should therefore be mined to meet only the local requirements of agriculture. It would be an extremely shortsighted and faulty policy to export it. The EP apatite is a mineral resource of immense value to the country whose exploitation must be carefully planned to serve the national interests.

It is understood that a U.S. mining company with worldwide mining interest has submitted a proposal for the exploitation of Eppawala phosphate ore which in the view of many of the Professional Associations in the country e.g. Sri Lanka Association for the Advancement of Science, The Institution of Engineers, Institute of Chemistry, National Academy of Sciences and most individual scientists and engineers is highly disadvantageous to the country and with highly adverse environmental impacts. This report examines the U.S. proposal and other proposals that have been submitted and determines independently the technically feasible options, which are more advantageous to the country.

The proposal of exploitation of the apatite mine is beset with many problems. Mines always cause damage to environment and minimization of such damage must be examined at length. Further, Eppawala phosphate ore is located in an agriculturally developed system, in an area of extreme historical importance and of archeological value in the proximity of natural monuments close to the Cultural Triangle sites with Sri Mahabhodhi and Ruwanweli Saya. Within the bounds of mining area are many ancient villages, which will be adversely affected. The immediate threat to Jaya Ganga or Yoda Ela cannot be overlooked. If the mining of ore damages the Jaya Ganga, it denigrades Sri Lankan history. Jaya Ganga is an engineering marvel that must be preserved for eternity as the heritage of mankind just as the Taj Mahal, the Pyramids or Ruwanweli Seya are preserved.

Exploitation by any international firms, which may not have high regard for the national monuments or be sensitive to national sentiments, should be perhaps examined with suspicion. Available records worldwide indicate that certain foreign mining companies are irresponsible. Their offers can be highly disadvantages to the country and of very great advantage to themselves. To quote from an international magazine, ***"they can be the most maverick in the world today."***

There is an alternate proposal submitted by another foreign company (Fertilizer Technology Group N.Z.) based on their study and investigations of the Eppawala Rock Phosphate (ERP), which is extremely beneficial to the country. To quote

(The Report by the Fertilizer Technology Group of New Zealand is titled " The Investigation of the Eppawala Phosphate Deposit – Assignment Report, January 1997 done through the Asian Development Assistance Facility, New Zealand Government Ministry of Foreign Affairs and Trade")

"A viable Single Super Phosphate (SSP) industry can improve this situation by providing cheaper, available fertilizers, while at the same time acting as import substitution

The payback period for the proposed investment is 2.5 years

Some of the proposed manufacturing units can be partially funded by the suppliers, thereby considerably reducing the total amount of capital needed to be raised

There will be some slight adverse social effects of implementing the project, but these will be well outweighed by the advantages

The technology in the proposed design, particularly the zero liquid effluent, will minimise any effect"

Source: *New Zealand Government Ministry of Foreign Affairs and Trade*
Fertilizer Technology Group
Asia Development Assistance Facility
The investigation of The Eppawala Phosphate Deposit
Assignment Report (January 1997)

The technology developed by New Zealand and proposed for this project mitigates environmental impacts by adopting World Bank standards for discharge limits. The design adopted eliminates liquid effluent disposal. They noted that the production of SSP is environment-friendly, a highly important factor in the evaluation of phosphate alternatives for local production.

The Conclusions and Recommendations of the New Zealand report are given in Annex 1.

1. World Phosphate Rock Demand into the Next Century

Herring and Fantel of the US Geological Survey, Denver, Colorado, USA, has modeled the depletion rate of world phosphate resource based on a variety of factors. Conclusions of the study are given in the abstract reproduced below. One important conclusion is " ... that the presently known reserves will be depleted within 50 years and the remainder of the reserve base will be depleted in the next 100 years......." This conclusion has a great bearing on how we shall exploit our own reserves at Eppawala. The irrefutable conclusion is that ERP deposit should be exclusively reserved for the country's use for generations to come. The main conclusions of the paper titled *"Phosphate Rock Demand into the Next Century: Impact on World Food Supply" and authored by* James *R. Herring' and Richard J. Fantel* ***are***

> *"A Vital and indisputable link exists between phosphate rock and world food supply. Phosphate rock is the source of phosphorus used to make phosphatic fertilizers, essential for growing the food needed by humans in the world today and in the future. We modeled the depletion of the known reserves and reserve base (which includes reserves) of phosphate rock based on various scenarios for increasing population and future demand for phosphate. Using these scenarios, the presently known reserves will be depleted within about 50 years, and the remainder of the reserve will be depleted within about the next 100 years. For this model, we used rates of growth of demand for phosphate rock of between 1 and 1.7 percent annually. We also examined demand rates that decrease over time toward demand stasis. Growth rate scenarios that stabilize demand at the year 2100 are little different from unconstrained growth. Demand stabilization by 2025 extends the reserve base by only about 50 years. Additional considerations could affect these depletion scenarios, causing them to be substantially too high or too low.* ***Nonetheless, the ineluctable conclusion in a world of continuing phosphate demand is***

that society, to extend phosphate rock reserves and reserve base beyond the approximate 100 year depletion in date, must find additional reserves and/ or reduce the rate of growth of phosphate demand in the future. *Society must: (1) increase the efficiency of use of known resources of easily minable phosphate rock; (2) discover new, economically-minable resources; or (3) develop the technology to economically mine the vast but currently uneconomic resources of phosphate rock that exist in the world. Otherwise, the future availability of present-cost phosphate, and the cost or availability of world food will be compromised, perhaps substantially."*

2. Agricultural Use of Phosphate Fertilizer

Phosphorus is a macro essential element for plant growth and increased yields of crop plants. Deficiency of phosphorus in the plant is difficult to be detected early and by the time it is detected, it is too late to be corrected. This is most relevant for annual crops. The early deficiency of P in annual crops can lower the final crop yield drastically It is the one of the reasons for adding phosphate fertilizer as a basal dressing to these crops and as a soluble form of phosphate.

In considering Phosphate fertilizer (PF) for crops, two important aspects need to be considered:

a. Solubility of the PF
b. The classification of the crop

Large differences exist between solubility of the less soluble PF such as Saphos or Eppawala Rock Phosphate from the readily soluble PF such as TSP, SSP & DAP. As regards phosphate nutrition, the distinction among crops is whether they are annuals or perennials which is a reference to the length of the growing cycle of the crop.

Plants are known to absorb Phosphate as the orthophosphate ion. When a PF is added to the soil either as rock-phosphate or soluble phosphate, it is known to undergo several chemical reactions. Definite chemical compounds such as ferric phosphate and aluminum phosphate are formed. But it is also known that there is sorption of phosphate ions on the surfaces of the oxide and clay particles. Phosphate fertilizers are generally banded close to root zone to cause high absorption by the crop for this reason. Solubility and concentration of phosphate ion in the soil solution is critically important in the absorption of phosphate by crop plants.

At 10^{-7} molar phosphate in soil solution, the concentration is known to be inadequate for growth of annual plants. It must be raised to at least 10^{-5} molar to satisfy plant requirements.

Absorption of phosphate whether it is perennial or annual crops is from this labile component of phosphate in soil. When insoluble phosphates are added to soil, reversion to soluble forms may take a longer time. But being less soluble themselves, the concentration of phosphate in soil solution is itself low. The phosphate chemistry of the soil and the insoluble phosphate and their interaction has a bearing on the length of the growing season of the crop. In case of annual crops the length of growing season is short and high concentration of phosphate in solution is necessary. It is known for instance that rice (crop of 4-month duration) absorbs its phosphate in the 3-4 weeks after planting or sowing. Solubility of the phosphate fertilizer is a less critical factor for perennial crops.

Annual Crops

The phosphate nutrition presents a different picture with annual crops. Plant growth is quick and the growing cycle is short viz. 4-6 months. Crops are known to take the most of PF during the early phase of growth. The weight of evidence seems to suggest that the soluble phosphates are more suitable for annual crops. This is not to say that rock-phosphate is to be excluded. Each annual crop reacts differently. Research alone could determine the response of any particular crop - whether rock-phosphate can replace the more costly soluble forms. It is known, in general, that in the case of potatoes, cereals and vegetables, rock-phosphate is found to be unsuitable. Removal of Phosphate by annual crops like potato and vegetables are high as they generate a high biomass within a short period of time. The shallow root system found in these plants requires soluble type of P fertilizers, which has been proven from experiments carried out by Nagarajah (1976) and Wijewardhana (1990) of the Dept. of Agriculture. Direct application of ERP is not suitable for annual crops due to its, low solubility in soil solution. SSP and PAPR can be used for all annual crops including potato and vegetables.

Perennial crops

Researchers have found that less soluble forms such as ERP satisfy the phosphate requirement of nature perennial crops. Recent research findings indicated that it is possible to use ERP in the immature phase of some perennial crops also. The reason is fairly clear in that it has a longer time period to absorb its phosphate. Annual absorption may itself be small and it has large root systems to exploit the soil volume. This is born out by research of the three crop institutes in the country. Both imported rock phosphate (Saphose) and locally available ERP are used at different stages in the cultivation of these perennial crops. In addition to those three crops, ERP, is suitable other perennials such as coffee, clove citrus, banana, pineapple, passion fruit and pepper.

Radioactive studies have shown that phosphate is concentrated at the growing points, perhaps because it is involved in phosphorylation and energy providing reactions. It is less a part of structural element of plant other than the cell membrane. As the plant grows, phosphate is remobilized within the plant to the growing point. Whatever is lost through harvest or by addition of dry matter is replenished by absorption throughout the year. Low levels of P in the soil solution seem to satisfy their requirements. In addition to this regular additions of Phosphate fertilizers may lower the P potential that can make P addition annually unnecessary as on some soils

Residual effects

The residual effect of soluble phosphate is generally reduced with the increasing time and regular addition of phosphate fertilizer becomes therefore necessary. But, addition of insoluble form of phosphate fertilizer enhances the residual effect. This is probable due to phenomenon called phosphate fixation. At any time only 10-5% phosphate added to the soil is taken up by plant, when soluble phosphates are used. DAP is one of the soluble P fertilizers made by using rock phosphate and is an expensive fertilizer. Therefore, it is recommended to use only in tea and rubber nurseries.

Experimental results of phosphate trials in the field are complicated by the residual effects and the build up of total and labile P levels in the soil so that interpretation of results needs to account for the history of phosphate fertilizer application to the soil. The Dept. of Agriculture has the responsibility for making fertilizer recommendations for all crops other than tea, rubber, and coconut.

Fertilizer recommendations by the Dept. of Agriculture for annuals are presently based on TSP. In their view TSP can be replaced by SSP when it is produced within the country and Dept. of Agriculture will change its recommendations.

3. Demand for rock phosphate

According to the recommendations made by relevant authorities, the annual requirement of rock phosphate fertilizer for the different sectors in the Sri Lankan Agriculture should be around 90,000 MT. But the annual consumption is around 50,000 MT due to various reasons. In addition to rock phosphates, nearly 40,000 MT of TSP is also used annually. Out of this amount, 45% is used in the paddy sector.

The World Bank has forecast that the world requirement for P fertilizers will increase tremendously by the year 2000 and the Asian region will consume 10.1% of the world total P fertilizers. It is expected that the demand for phosphate fertilizers in Sri Lankan agriculture will increase by the year 2000. As a result, prices for P fertilizers are expected to increase and therefore more foreign exchange will be required to meet the increasing demand. At the present rate of consumption it is estimated that the potential use of ERP in the future will be more than 50%, 42% and 20% of the total demand for P fertilizer for rubber, tea and coconut respectively.

4. Exploitation of Eppawala Phosphate deposit-Some basic facts

1. Current use of phosphate rock annually stands at 50,000 mt. The growth of local demand will depend on agricultural policies. No assessment of demand growth is made here.

2. Being a non-renewable naturally occurring mineral, Rock Phosphate is a dwindling resource worldwide and should therefore be treated as an asset to the country and be wisely utilized.

3. The surface geological, mineralogical and geochemical studies (Dahanayake, 1995) at the Eppawala Phosphate Deposit have revealed the existence of **more soluble** primary apatite crystals of maximum length that can sometimes exceed 50cm (with more than 35% P_2O_5 and less than 1% Iron and Aluminium) in a **less soluble** ferruginous-siliceous fine grained secondary phosphate matrix (with Fe and Al content that can sometimes exceed 15%). On the weathered surface of the deposit it is possible to extract the high quality primary apatite crystals of different sizes from the matrix. The matrix in its present form can be used for long term crops such as tea, rubber and coconut as at present. However, a detailed geological survey is crucial to (i) determine the exact distribution of primary apatite crystals and the secondary phosphate matrix on the weathered surface and (ii) assess the grade and extent of the ore in the sub-surface parts of the Eppawala Phosphate deposit.

4. Chloride content in Eppawala apatite is high while the F content is low. Thus environmental effects due to leached F will not be a significant factor.

Possibilities for producing soluble phosphate fertilizer

1. Single Super Phosphate could be obtained by treating rock phosphate with sulphuric acid.

2. Triple Super Phosphate – produced by the action of phosphoric acid on rock phosphate and contains three times the equivalent of phosphate compared to SSP.

3. Nitrophos-when nitric acid is used for acidulation nitrophos is obtained.

4. Rhenania phosphate: when rock phosphate is fused with sodium carbonate this form is obtained.

5. Diammonium phosphate - Here phosphoric acid produced by the action of sulphuric acid on rock phosphate is reacted with ammonia to produce diammonium phosphate.

6. Hydrochloric acid is used for producing a product which is soluble but because it is hygroscopic, ammonium sulphate is added to produce a non hygroscopic fertilizer. This provides the nutrient nitrogen in addition to phosphorus. However, ammonium sulphate is not commonly used as a nitrogen source since cheaper urea is available and this is a disadvantage of this process.

Out of these processes, production of Single Super Phosphate is the most advantageous and cheapest since sulphuric acid is the cheapest available mineral acid; the process is technologically simple.

Diammonium Phosphate is high quality phosphate fertilizer owing to its ready solubility, high phosphorus content and also because it provides an additional nutrient, nitrogen. However the process of production involves setting up of ammonia and phosphoric acid plants (in addition to a sulphuric acid plant). It is capital intensive and also creates more environmental hazards.

The HCl process is viable only if a hydrocholoric acid plant is available, locally.

The other process mentioned above are not economically viable.

Economic considerations

Only two proposals

(1) A U.S. mining company's proposal involving the production of TSP, and

(2) A New Zealand proposal to produce SSP.

are evaluated here.

U.S. mining company proposal

The essential features of this proposal:

Total capital expenditure: US $425 million
Total value of Eppawala Rock Phosphate mined over 30 years (Sri Lanka's contribution) US $ 673 million- f.o.b. value.

Direct monetary benefits to Sri Lanka

(a) Royalty of 5.5% of Morocco International price on all raw rock phosphate mined for export (3.6 million tons) and used locally for diammonium phosphate manufacture (22.5 million tons)-US $ 37 million.
(b) Dividend on 10% free equity over 30 year period (US $ 70 million)

Indirect monetary benefits

(a) 5% tax for the first 12 years and 15% tax thereafter giving a total of US $ 74 million.
(b) Defense levy US $ 1.3 million
(c) Ports Authority earnings US $ 137 million.
(d) Foreign exchange revenue from all exports of DAP US $ 152 million.
(e) Savings on fertilizer subsidies US $ 7 million

(f) Social and infrastructure benefits.

i. 1000 people employed.
ii. Local farmers will get DAP at 50% of the world market price.
iii. Improvement of rail tracks from Eppawala to Trincomalee.
iv. Improvement of facilities at Trincomalee port.

Shortcomings of the U.S. mining company proposal

1) The total cost of the project over a 30 year period is US $ 1098 million (425 milllion invested by U.S. mining company +673 million for the cost of rock phosphate mined) out of which Sri Lanka gets a direct income of only US $ 107 million. This is a dismally poor deal since Sri Lanka's investment in kind represents a share of over 60%. Even this value will actually be lower due to rate of interest. Similarly the indirect benefit at the end of thirty years of US $ 364.3 would give a much lower discounted present value. The total monetary benefits to Sri Lanka even without taking this depreciation into account would be 107+364.3=471.3 US $ million while Sri Lanka loses a resource valued at US $ 673 million forever. Thus Sri Lanka gets an extremely poor deal from this proposal.

2) The capital commitment by the overseas investors given in the original submission was 260 million USD and this has become 425 million in the present proposals. This appears to be a ploy to get a higher equity position for them in the joint venture. Foreign partners have capitalized on the ignorance of the Sri Lanka government's negotiating team.

3) The estimated capital requirements for an operation involving the production of 0.6 million tonnes of DAP per annum is 273 million USD which compares well with the originally quoted price of 260 million USD. In Jordan, a project involving a similar processing plant cost only US $ 160 million and on the same scale our proposed processing plant in Trincomalee should only be around US $ 204 million

4) The investors agree to provide DAP fertilizer to local farmers at 50% of the world market price. The current world market price is around US $ 463 per ton. The cost of production of a ton of DAP is only 118 US $ whereby the company makes a profit of 100% on its sales of DAP to local farmers.

5) There is pollution at the site of mining where considerable ecological damage is expected. The plants at Trincomalee will also contribute towards pollution and the disposal of phosphogypsum produced at the rate of 1 million tons annually would pose an environmental hazard of enormous significance. The 0.5 million US $ committed as an environmental bond is too small for a project of this magnitude.

6) Diammonium Phosphate as a fertilizer is required only in small amounts in Sri Lanka (ca. 1000 tons/ year). It leaches rapidly polluting the underground water table. The drainage of soluble phosphate fertilizers into the sea is reported to have damaged coral reefs in the USA.

The New Zealand Proposal

New Zealand Government Ministry of Foreign Affairs and Trade
Fertilizer Technology Group
New Zealand
Asia Development Assistance Facility
The investigation of The Eppawala Phosphate Deposit
Assignment Report
January 1997

A proposal for the exploitation of ERP was submitted to the Sri Lankan government by the Ministry of Foreign affairs and Trade of the New Zealand government under its Asia Development Assistance Facility in January 1997. The essential features in this proposal are:

1. The nature of the Eppawala deposit strongly favours the production of SSP over other products, particularly those based on phosphoric acid for which the ore is unsuited.

2. The total investment for an SSP production facility is 20 million dollars with a payback period for the investment of only 2.5 years.

3. The technology in the proposed design, particularly the zero liquid effluent will minimize any serious environmental effects

4. Despite the impurities present in the phosphate it has been demonstrated that good quality SSP can be produced. It was also shown that this is a suitable fertilizer for Sri Lankan agriculture.

5. The plant value calculated under the headings of acid plant, SSP plant, dispatch plant, grinding plant, granulation plant and other buildings cost 17.4 million US $. This along with a working capital of 3.1 million US $ gives the total cost of the project at 20.5 million US $ which is a fraction of the cost of expenditure under the U.S. mining company proposal. Basic production cost is calculated at $ 40.67/ton of SSP.

6. Exploration area is limited to about 2.5 square km as against the 56 sq.km land that will be used in the joint venture with the U.S. mining company.

7. The ore will last for over 200 years under this proposal compared to the 30 years period for exhausting the reserve under the U.S. mining company proposal.

5. Processing of ERP to a soluble form - SSP

Source: Fertilizer Manual, IFDC, Muscle Shoals, Alabama, USA 1983

Single Super Phosphate Fertilizer

Single Super Phosphate, also called normal or ordinary Super Phosphate or acid phosphate, has been the principal phosphate fertilizer for more than a century and supplied over 60% of the world's phosphate as late as 1955. Since then its relative importance has declined steadily; in 1975 it supplied only 20% of the fertilizer phosphate in the noncommunist world (data for some communist countries are incomplete). The decline in actual tonnage has been small, but most of the new facilities have been built to produce other, higher analysis products. For the world as a whole, including communist countries, TVA estimated 1972 SSP production at 7.87 million tons of P_2O_5 fertilizer production, and projected production of 7.4 million tons in 1978 which would be about 25% of the total phosphate fertilizer production (1). Thus, SSP is still an important phosphate fertilizer and is likely to remain so even though its relative importance will decrease.

The advantages of SSP are:

1. The process is simple, requiring little technological skill and small capital investment.
2. The economies of scale are minor, thus small plants can be economical.
3. Since the process is not capital intensive, there is little advantage in a high percentage utilization of capacity; in fact, many SSP plants operate on a planned seasonal schedule.
4. The fertilizer effectiveness of SSP is unquestioned; in fact, it is a standard of comparison for other phosphate fertilizers.
5. SSP supplies two other nutrient elements, sulfur and calcium, which are sometimes deficient in the soil.

SSP vs TSP & DAP

Despite these impressive advantages, the disadvantage of low analysis, 16%-22% P_2O_5, and consequently relatively high shipping costs have caused declining interest in its production because the delivered cost at the farm level is usually higher per unit of P_2O_5 than that of TSP or ammonium phosphates when purchased abroad. When SSP is manufactured internally, in a small country as ours, local distribution costs are not a determining factor. Moreover it supplies S and Ca, which have to be added to the soil at regular intervals if TSP or DAP is used. Local TSP manufacture from ERP is not an option because larger quantities of sulphuric acid, and phosphoric acid need to be imported. The high chlorine content of ERP precludes manufacture of Phosphoric Acid, needed to manufacture TSP. Consequently manufacture locally of TSP is unviable. When SSP is manufactured locally TSP will not be recommended by the Dept. of Agriculture for short-term crops. (Annex 2). For the same reason, importers are unlikely to get down TSP; farmers are not likely to ignore the recommendation of the Dept. of Agriculture. DAP although an equally good fertilizer for annuals is very expensive and its manufacture from ERP should not be considered. DAP is not a recommended phosphorus fertilizer.

SSP will still be a logical choice in several situations such as:

1. Where both P_2O_5 and sulfur are deficient, SSP may be the most economical way to meet these needs. This is the case in much of Australia and New Zealand, some parts of the United States, and Brazil. It is likely that more locations where sulfur is deficient will be identified.

2. In small countries or remote regions where the demand is insufficient to justify and economical scale of production of concentrated phosphate fertilizers and where importation is expensive, SSP can be the most economical means for supplying local needs.

3. In many cases, SSP can be an attractive way to utilize the byproduct, sulfuric acid, which cannot be used to produce more concentrated products because the quality or quantity of the acid is unsuitable. Likewise, SSP can utilize deposits of phosphate rock that are too small to justify a more expensive plant.

Suitability of Phosphate Rocks

Since the grade of the rock determines the grade of the product SSP, a high-grade rock is desirable. Reactivity is also important; unreactive rocks must be ground more finely. It is extremely difficult to produce SSP from some igneous apatites. Iron and aluminum compounds can be tolerated up to a point, although they decrease the P_2O_5 water solubility. Silica has no adverse effect other than decrease in grade. An increase in CaO: P_2O_5 ratio increases the sulfuric acid consumption per unit of P_2O_5 and decreases the grade. High-chloride rocks (up to 0.5% Cl and perhaps higher) can be used without serious disadvantage since corrosion is not a serious problem in SSP production.

Chemistry of SSP

The main overall chemical reaction that occurs when finely ground phosphate rock is mixed with sulfuric acid in the manufacture of SSP may by represented by the following equation.

$$Ca_{10}F_2(PO_4)_6 + 7H_2SO_4 + 3H_2O = 3Ca(H_2PO_4)_2 . H_2O + 7CaSO_4 + HF$$

It is generally agreed that the reaction proceeds in two stages: (1) the sulfuric acid reacts with part of the rock, forming phosphoric acid and calcium sulfate and (2) the phosphoric acid formed in the first step reacts with more phosphate rock, forming monocalcium phosphate. The two reactions take place concurrently but the first stage is completed rapidly while the second stage continues for several days or weeks.

The calcium sulfate is mainly in the anhydrous form. The hydrogen fluoride reacts with silica in most rocks, and part of it is volatilized, usually as SiF_4. The remainder may form fluosilicates or other compounds in the SSP. Usually 25% or more of the fluorine is volatilized and must be recovered to prevent atmospheric pollution. In some cases recovery as salable fluorine compounds is feasible, but more often the scrubber liquor is disposed of in a pond by neutralizing it with lime or limestone.

"Kotka Super Phosphate" is a mixture of Super Phosphate and phosphate rock. It is named for the city of Kotka, Finland, where it was originally made. It has the advantages that little curing is needed, and the free acid content is low. Its effectiveness generally is equal to that of equivalent amounts of fully acidulated Super Phosphate plus raw phosphate rock applied separately.

Table 1 shows the chemical composition of one sample of Kotka Super Phosphate and five typical samples of SSP. SSP usually contains 6%-10% moisture; therefore its grade can be increased by drying.

TABLE 1. COMPOSITION OF SINGLE SUPER PHOSPHATES

	Composition, % by Weight			
	P_2O_5			
Source of Rock	Total	Available	Water Soluble	Free Acid
Florida	19.9	19.6	17.5	2.4
Florida (granular)	21.5	20.7	17.4	0.6
Morocco	19.8	-	18.8	2.0
Morocco	21.4	20.2	-	1.7
Ocean Island	22.8	-	20.8	4.6
Morocco and Kola (Kotka)	22.8	14.6[b]	14.5	1.3

a. Super Phosphate plus additional phosphate rock.
b. Alkaline citrate soluble.

"Serpentine Super Phosphate" has been produced in New Zealand by mixing serpentine (a mineral consisting of hydrous magnesium silicate) with SSP. The usual proportion is one part of serpentine to four parts of SSP. The serpentine improves the physical properties of SSP by reacting with the free acid, and it supplies magnesium to crops. Various other minerals or chemical compounds sometimes are added to supply magnesium or micronutrients that may be needed locally.

Production Methods

The manufacture of Super Phosphate involves the following three (or four) operations.

1. Finely ground phosphate rock (90% <100-mesh) is mixed with sulfuric acid. With rock of 34% P_2O_5 content, about 0.58 kg of sulfuric acid (100% basis) is required per kilogram of rock. Sulfuric acid is available commercially in concentrations ranging from 77% to 98% H_2SO_4. The acid usually is diluted to 68%-75% H_2SO_4 before it is mixed with the rock, or in the case of the cone mixer, the water may be added separately to the mixer. When concentrated sulfuric acid is diluted, much heat is generated; many plants cool the acid in heat exchangers to about 70^0 C before use.

2. The fluid material from the mixer goes to a den where it solidifies. Solidification results from continued reaction and crystallization of monocalcium phosphate. The Super Phosphate is excavated from the den after 0.5-4.0 hours. At this time it is still somewhat plastic, and its temperature is about 100^0C.

3. The product is removed from the den and conveyed to storage piles for final curing, which requires 2-6 weeks, depending on the nature and proportions of the raw materials and the conditions of manufacture. During curing, the reaction approaches completion. The free acid, moisture, and unreacted rock contents decrease, and the available and water-soluble P_2O_5 contents increase. The material hardens and cools. The product from storage is fed to a disintegrator, usually of the hammer-mill or cage-mill type. The product from the mill is discharged onto an inclined screen of about 6-mesh size. The material that fails to pass the screen is returned to the mill for further grinding.

4. If granular Super Phosphate is desired, the product is granulated either before or after it is cured. Granulation before curing has the advantage that less water or steam is required. After granulation, the product is dried in a fuel-fired dryer and screened; the fines are returned to the granulation unit.

For many years SSP was produced only by batch mixing methods; however, most modern plants use continuous mixing and denning processes. There is a wide variety of both batch and continuous mixers and dens; no attempt will be made to describe them all. More detail may be found in the book, <u>Super Phosphate: Its History, Chemistry and Manufacture (2)</u>

One popular batch system is shown in figure 1. The rock and acid are weighed and discharged into a pan mixer, which may have a capacity of 1-2 tons per batch. After mixing about 2 minutes, the fluid mix is discharged into a box den, which may hold 10-40 tons. When the den is filled, one side is removed and the den is advanced slowly on a track to a mechanical cutter, which shaves thin slices of Super Phosphate from the block and discharges them to a conveyor or elevator.

With automated weighing and pan discharge, 3-minute mixing cycle is feasible; with a 2-ton mixer, a 40-ton den can be filled in 1 hour. Some plants have two dens so that one is being filled while the other is being emptied; this gives a production rate of 40 tph.

Figure 2 shows a flow diagram of a popular type of continuous den; the Broadfield den is a well-known example. The mixer may be a cone mixer, as shown a paddle mixer (pugmill), or sometimes a cone mixer discharging into a paddle mixer. Retention time in such dens usually ranges from 30 minutes to 1 hour and can be varied by varying the speed of the slat conveyor. This type of den is also suitable for making Triple or enriched Super Phosphate.

The production of a ton of SSP of 20% available P_2O_5 content would require 626 kg of ground phosphate rock (34% P_2O_5), 390 kg of sulfuric acid (93% H_2SO_4), and 90 kg of water. The reaction generates considerable heat. Approximately 8%-10% of the weight of the ingredients (water vapor and volatiles) is lost in the manufacturing and curing steps.

A typical continuous mixer plant to produce 20 tons of non-granular Super Phosphate per hour would have a 60-KW electrical load.

By applying prevailing unit costs, a rough approximation of the direct cost of producing superphosphate in a specific location can be obtained. The operating requirements per ton of superphosphate are:

Phosphate rock, ton	0.626
Sulfuric acid, (93% H_2SO_4), ton	0.390
Water, ton	0.1
Electricity, kWh	3[a]
Operating labor, man-hour	0.15
Supervision, man-hour	0.017

a. Does not include rock grinding, which requires 7-25kWh/ton of rock depending on rock hardness and desired fineness.

The capital cost for SSP production will vary widely. While the process equipment itself is relatively inexpensive, a self-sufficient plant including sulfuric acid production, phosphate rock grinding, storage curing, and granulation could be as expensive as a plant for making concentrated fertilizers (TSP or DAP) for an equal P_2O_5 output. However, SSP plants often use byproduct sulfuric acid derived from a plant that is not a part of the SSP plant. Also, small SSP plants may purchase sulfuric acid from a larger plant that supplies several customers.

When several SSP plants are planned or in use, the phosphate rock may be ground at the mine or at a port and shipped to individual plants to take advantage of economies of scale in grinding. When in-plant rock grinding facilities are necessary, the cost depends on the initial size and hardness of the rock.

Storage curing costs will depend in part on the extent of fluorine emission control that is required.

Whether the SSP should be granulated depends on local preference. In some countries nongranular SSP is acceptable. Also, in many cases the SSP will be used as an ingredient for producing granular compound fertilizer.

When granular SSP is desired, the ex-den granulation system described in chapter XIV is suitable. According to Sinte Maartinsdijk, the recycle ratio in this plant was 0.63:1.0 (3). Referring to figure 14, chapter XIV, the battery-limits cost of a plant for granulating 800 tpd would be about $3.2 million. In accordance with table 2, chapter XIV, the battery limits cost of the plant, not including sulfuric acid production facilities or final product storage, would be:

Item	Cost, U.S. $ Million
Phosphate rock grinding	1.0
Acidulation	0.8
Granulation	3.2
Storage curing	1.2
	6.2

Typical process requirements for granular SSP (800 tpd) and illustrative costs are:

	Requirement Per ton of SSP	Example of Cost: Unit Cost, $	Example of Cost: $/ton of SSP
Phosphate rock (33% P_2O_5)	0.626 tons	25	15.65
Sulfuric acid (93% H_2SO_4)	0.390 tons	27.90	10.88
Electricity	33.5kWh	0.015	0.50
Labor[a]	0.208 man-hour	15.40	3.20
Fuel	62 kcal	0.008	0.50
Steam[a]	55kg	0.02	1.10
Water[a]	85 kg	neg.	neg.
Capital related costs			6.21
			38.04

a. Requirements from reference 3
b. Labor-related costs including overhead and chemical control.
c. Battery-limits cost x 1.5 x 17.67% ÷ 264,000 tpy.

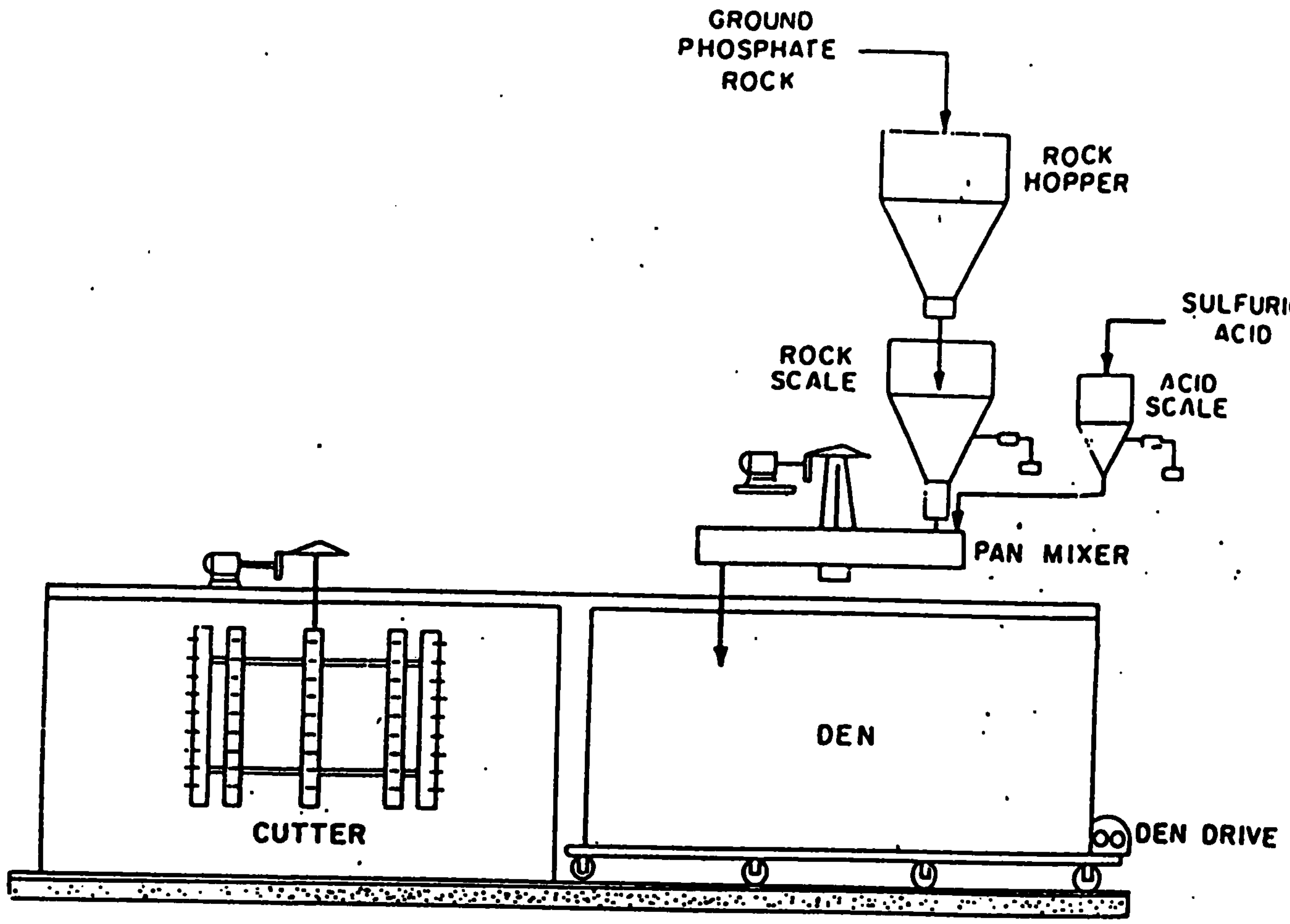

Figure 1. Batch Manufacture of Single Superphosphate.

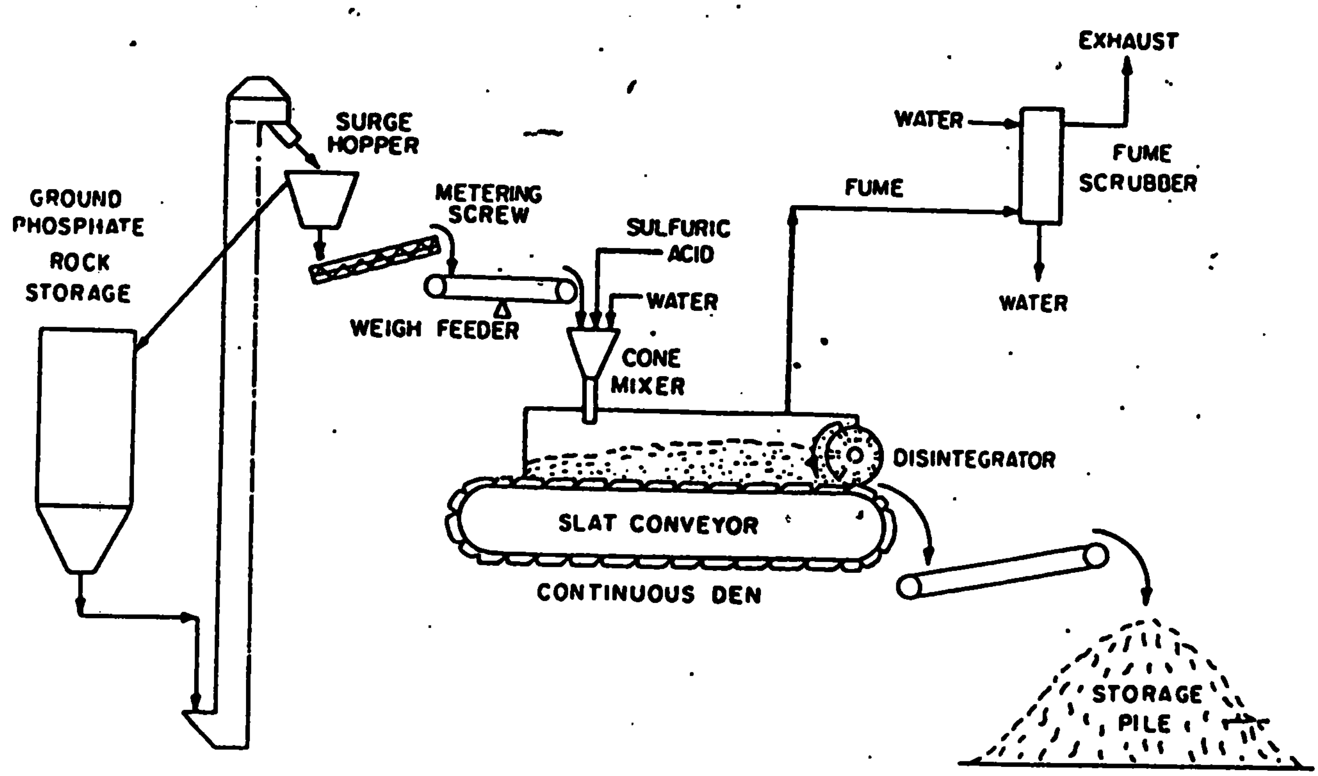

Figure 2. Continuous Manufacture of Single Superphosphate.

P_2O_5, is equivalent to about $190/ton of P_2O_5 which may be compared with $200-$213 for TSP, estimated in chapter XIV by similar methods and unit costs. This small advantage would be more than offset by the cost of bagging, transportation, and storage. If these costs amounted to only $20/ton, they would add $100/ton of P_2O_5 to SSP as compared with $43.50 for TSP.

Thus, it may be concluded that large-scale production and distribution of SSP is seldom economical in comparison with TSP or DAP, unless there are special circumstances such as an agronomic requirement for sulfur which would render the SSP more valuable.

On the other hand, small SSP plants to serve small local markets can be economical where suitable raw materials are available, and the alternative of importing more concentrated materials is very expensive.

Conclusion

On the basis of this presentation by IFDC, SSP is the Phosphate fertilizer of choice for Sri Lanka to be manufactured from ERP.

6. Demand for SSP

Currently TSP is being used because shipping costs are higher for SSP because of its relative higher bulk. SSP could replace TSP if SSP is locally produced. The transport cost factor is less important for locally manufactured SSP. The annual demand for SSP (based on current usage of TSP) is estimated at 350,000 tons.

7. Official Position of the Department of Agriculture regarding ERP and SSP

Dept. of Agriculture states its position agreed to by all its seven soil scientists thus:

1. *If Single Super Phosphate (18-21% P_2O_5) out of ERP is manufactured, it could be used for the production of annual food crops.*
2. *SSP manufactured using ERP has to be tested in the field continuously for 2-4 seasons before arriving at conclusive recommendations.*
3. *The ERP reserve should be judiciously used keeping in mind of the dwindling world reserves of phosphatic materials.*

4. ***The plantation crops depend on ERP to about 98% of the requirement. Dismantling the ERP supply could result in the necessity to import this material from outside at enormous costs in 30 years time.***

5. *The price factor in SSP to be produced has to be evaluated for its successful use and sustainable production.*

The volume of imports of fertilizers to the country is given in Annexes 3a and 3b.

1.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine if the somewhat unusual Eppawala phosphate rock deposits could be responsive to New Zealand fertilizer technology and be the basis of an indigenous phosphate fertilizer industry with all its consequent benefits to the Sri Lankan economy.

The following fundamental points have been established :-

(i) There is adequate phosphatic mineral to provide the volume necessary to be the underpinning of a substantial phosphate industry suitably sized for virtual replacement of phosphate fertilizer imports.

(ii) Despite the impurities in the phosphate it has been demonstrated that good quality superphosphate can be produced. It has been shown that superphosphate is a suitable fertilizer in Sri Lankan agriculture.

(iii) It has been shown that the process technology advanced can operate at negligible pollution levels and on a self sufficient energy basis.

(iv) A full works has been designed in outline and plant and buildings specified.

(v) The projected plant will provide significant skilled and semi-skilled employment in an area where this is needed.

(vi) The plant as proposed is without significant adverse sociological effects.

(vii) Costing and pricing has been fully investigated and very satisfactory profitability demonstrated.

(viii) Reasons have been advanced for the view that this technology and the products resulting represent a more appropriate and immediately realisable objective for the utilization of the Eppawala deposit than any alternative scenario.

(ix) Probable financing for a significant part of the necessary investment has been sourced.

(x) In summary all necessary conditions have been successfully dealt with for the establishment of a significant phosphate industry in Sri Lanka which will be very beneficial to agriculture and the economy in general.

The next and final step in this study will be to present this report to our associates in Sri Lanka and to promote the establishment of the industry as designed.

Annex 1 contd...

It is proposed that members of the New Zealand Fertilizer Technology Group will devote a considerable effort to the promotion of the proposed industry with a team visit to Sri Lanka as the initial phase of this programme.

Success in this endeavor will lead to the export of New Zealand technology, engineering consultancy and very significant engineering equipment and fabricated componentry.

The NZFTG partnership is in the last stages of design and early stages of construction of a fertilizer industrial development of comparable size at Ayutthaya in Thailand and is very well placed to use this study as the framework on which to erect a similar venture in Sri Lanka.

Annex 2

MEETING TO DISCUSS THE FEASIBILITY OF USING ERP IN FOOD CROPS PRODUCTION

Fertilizer Unit 28.04.99 - 10.30 Am.

Present;

Dr. R. Seneviratne
Mr. S.T. Dissanayake
Dr. J.D.H. Wijewardane
Dr. S. Wijesundera
Dr. D.B. Wickramasinghe
Dr. M.A. Lathief
Dr. D.M. Jinadasa
Mr. D.M. Sirisena

Decisions made on the utilization of ERP

1. If Single Super Phosphate (SSP) 18 - 21% P_2O_5 out of ERP, is manufactured it could be used for the production of annual food crops.

2. Single Super Phosphate manufactured using ERP has to be tested in the field continuously for 2 - 4 seasons before arriving at conclusive recommendations.

3. The ERP reserve should be judiciously used keeping in mind of the dwindling world reserves of phosphatic materials.

4. The plantation crops depends on ERP to about 98% of the requirement. Dismantling the ERP supply could result in the necessity to import this material from outside at enormous costs.

5. The price factor in SSP to be produced has to be evaluated for its successful use & sustainability.

Annex 3 a

Annual use of fertilizer products and nutrients in all crops in Sri Lanka 1970-1995 ('000 MT)																
Year	SA	UREA	TSP	IRP	LRP	MOP	NPK	KIEZ	DOL	OTHER	TOTAL	N	P	K	Mg.	Total
1970	145.6	42.9	8.7	54.7	-	53.7	13	-	-	16	334.6	51	20.7	33.4	-	105.1
1971	137	59.6	11.9	50.8	-	53.4	14	-	-	15.2	341.9	57	21.1	34.2	-	112.3
1972	107	61	10.4	36.9	-	47.6	-	-	-	15.3	278.2	51.2	17.5	31.2	-	99.9
1973	117	68.2	19.6	39.7	-	48.2	17.7	-	-	14.4	324.8	56.8	22.7	31.6	-	111.1
1974	118.1	58.6	7.2	30	-	46.1	25	-	-	9.6	294.6	55.3	15.3	31.3	-	101.9
1975	83	43.7	1	27	-	31.5	17.4	-	-	7	210.6	40.1	10.8	21.5	-	72.4
1976	91.4	68.3	7.7	33.1	-	44.7	10.8	-	-	8.1	264.1	52.3	14.5	28.5	-	95.3
1977	80.3	103.6	20.4	30.7	-	35.8	19.4	-	-	7	297.1	65.4	22.4	23.8	-	111.6
1978	110.3	123.9	24.4	42.3	-	47	21.6	-	-	10.4	379.9	80.9	28.7	30.8	-	140.4
1979	104.8	116	9	39.3	7.8	50	34.9	-	-	10.3	372.1	77.2	26.1	34.3	-	137.6
1980	97.5	150.3	26.2	37.8	9.2	67.1	10.2	-	-	11.4	439.7	91.6	31.4	46.1	-	169.1
1981	75.1	126.6	26.4	22.1	14.7	61.3	29.9	-	-	10.9	367	75.6	27.4	41.2	-	144.2
1982	57.3	142.8	33.1	19.9	14.4	66.9	32.7	-	-	8.1	375.2	79.4	30.4	45	-	154.8
1983	76.4	141	32.7	24.6	12.8	71.8	33	-	-	12.9	405.2	82.5	31.1	48.1	-	161.7
1984	87.8	165.8	37.2	35.96	16	84.9	27.9	-	-	15.6	470.8	96.1	36.2	55.3	-	187.6
1985	81.8	179.8	41.5	35.4	14.4	87	24.8	3.9	17.4	7.5	493.5	101.2	37.2	56.2	-	194.6
1986	74.2	189.1	52.1	29.4	12.8	85.3	27.1	3.7	15.6	7.8	497.1	104.1	40.2	55.6	-	199.9
1987	87.9	182.6	45.4	27.5	19.9	90.6	23.4	5.2	13.8	9	505.3	103.7	38.3	59.2	-	201.2
1988	106.4	179.3	46.3	24.5	23	97	25.5	7	7.6	8.6	525.2	106.1	39	62	-	207.1
1989	86	192.8	52.4	13.6	26.5	93.8	35.3	7.1	7.5	7.2	522.2	108.5	41.4	61.6	3.2	214.7
1990	88.4	159	35	18.7	21.2	79.5	12.5	7.9	6.4	8.5	437.1	92.3	29.2	49.5	3.2	174.2
1991	100	161	39.9	17.6	19.4	80.5	14.4	6	6.3	8.6	453.7	95.7	30.9	50.5	2.7	179.8
1992	112.8	169.2	37.2	16.7	23.6	81.9	13.2	6.2	7.3	7.7	475.8	102.2	30.4	51.1	3	186.7
1993	118.5	193.1		16.63	25	91.3	25	5.6	7.7	12.4	548.1	115	39.8	58.5	2.3	216.2
1994	103.4	211.4		14.6	24.3	96.2	11.4	5.6	7.4	5	532.7	119.5	35.5	59.5	2.8	217.4
1995	94.2	208.4	50.9	14.4	22.1	91.6	9.6	4.6	7.7	5.9	509.4	116.1	35	56.4	2.7	210.2

Source: National Fertilizer Secretariat

Annex 3 b

Estimated Fertilizer Consumption by Crop Sectors in 1995 (MT)										
Fertilizer	**Paddy**	**Tea**	**Rubber**	**Coconut**	**OFC**	**EAC**	**Tobacco***	**Others****	**Total**	**Share**
Urea	157,609	34465	3148	3987	4565	662	9	3976	208420	40.91
SP	16064	41610	1865	5774	14799	1686	11	12379	94188	18.49
TSP	34578	207	3	391	10072	101	0	5506	50858	9.98
IRP	223	5421	2292	3035	734	1055	0	1591	14351	2.82
ERP	2250	10459	3273	4608	425	234	10	808	22067	4.33
MOP	39951	22471	3048	11304	7291	1020	9	6530	91624	17.99
NPK*	5167	0	0	0	0	0	4465	0	9632	1.89
KIEZ	60	2427	872	529	363	83	0	234	4568	0.9
DOL	651	1423	447	3471	1293	42	1	423	7751	1.52
*7:18:15:2 = 2265mt & 10:20:20 =220mt										
**Other crops and unspecified sales										

Source: National Fertilizer Secretariat

ABBREVIATIONS

ERP	- Eppawala Rock Phosphate
SSP	- Single Super Phosphate
TSP	- Triple Super Phosphate
SAB-PAPR	- Sulphuric acid based-Partially acidulated rock phosphate
DAP/MAP	- Diammonium phosphate/Monoammonium phosphate
PF	- Phosphate Fertilizer
IRP	- Imported Rock Phosphate
LRP	- Local Rock Phosphate

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