

## Potential of Eppawala Apatite as a directly applied low-cost fertilizer for rice production in Sri Lanka

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### Abstract

Apatite in Sri Lanka is mined from Eppawala (Eppawala Rock Phosphate or ERP). The finely ground product is used as a direct application fertilizer for tea, rubber and coconut. ERP is an indiscriminate mixture of more soluble primary crystals and a less soluble secondary phosphate matrix rich in ferruginous and aluminous compounds with an average P<sub>2</sub>O<sub>5</sub> content of 30%. The primary crystals can easily be separated from the groundmass by mechanical separation to produce selectively mined primary crystals (SERP) which has higher P<sub>2</sub>O<sub>5</sub> (35 to 42%) and lower R<sub>2</sub>O<sub>3</sub> contents (around 1%) than the matrix. The ground SERP shows promise, as measured using yield and bicarbonate-extractable soil P, as fertilizer for rice grown in lowland and midland acid soils. In the second crop residues of SERP produced larger yields and bicarbonate-extractable P than Triple super phosphate (TSP) for the first crop. TSP is imported and its price is four times that of SERP. Therefore SERP is a potentially more profitable alternative fertilizer for TSP for rice on Sri Lankan acid soils.

### Introduction

The largest rock phosphate deposit in Sri Lanka, estimated to be about 40 million metric tonnes (Jayawardene, 1976) is at Eppawala in the North Central Province. At the current rate of consumption, the deposit should provide sufficient rock phosphate for a few centuries. The deposit is different from other known phosphate ores in the world. It comprises primary apatite crystals varying in size from a few microns to several tens of centimeters, with maximum P<sub>2</sub>O<sub>5</sub> contents exceeding 40%. Large quantities of apatite can be easily mined from a loose, unconsolidated matrix. The R<sub>2</sub>O<sub>3</sub> content of primary apatite crystals can be as low as 1% (Dahanayake and Subasinghe, 1991). The commercial Eppawala rock phosphate (ERP) is not selectively mined. It is therefore an indiscriminate mixture of primary crystals and the finer secondary phosphate matrix, in which the R<sub>2</sub>O<sub>3</sub> content exceeds 5%. ERP is currently being used as a direct application fertilizer for tea, rubber and coconut in varying pro-

portions together with imported rock phosphate (IRP). This paper reports preliminary experiments that compared powdered selectively mined ERP (SERP) and the commercial ERP with triple superphosphate (TSP) as fertilizers for growing rice. The experiments were conducted on different soil types in Sri Lanka. SERP showed promise as an alternative fertilizer to TSP for rice.

### Present status of direct application of Eppawala Rock Phosphate

In Sri Lanka, ERP is used as a direct application fertilizer for tea, rubber and coconut grown on acid soils (Sri Lanka Review of Fertilizer, 1992; Appleton, 1994). Recommendations for the different crops are as follows:

- Coconut: The Coconut Research Institute has recommended from November 1989, that 50% of the

P requirements of adult coconut palms be fertilized with ERP

- Rubber: The Rubber Research Institute also recommends 100% replacement of Imported Rock Phosphate (IRP) with ERP for mature rubber and 50% for immature rubber.
- Tea: The Tea Research Institute recommends 100% substitution of ERP for IRP in both mature and immature tea (Sivasubramaniam et al., 1981).
- Rice and vegetables: ERP is considered a poor source as a directly applied fertilizer for all short term crops except under upland acid soils where slight responses were observed (Sri Lanka Review of Fertilizer, 1992 ; Wijewardena and Amarasiri, 1990; Appleton, 1994). However, Santhy and Kothandaraman (1988) have demonstrated that ERP mixed 1:1 with TSP proved to be an effective, cheaper source of P than TSP alone for rice-rice-pulse cropping systems.

ERP contains an aluminous-ferruginous-siliceous fraction which is unlikely to be effective for rice and vegetables. However, the aluminous-ferruginous-siliceous fraction can be removed by selectively mining the finer apatite crystals (selectively mined ERP or SERP). SERP comprises about 70% of the Eppawala deposit (Dahanayake and Subasinghe, 1991; Dahanayake, 1994). The few experiments conducted with short term crops such as rice have been done with the commercially available ERP which has not been selectively mined (Nagaraja *et al.*, 1979; Wijewardena and Amarasiri, 1990). It is therefore not known how effective SERP is for rice and vegetables. This is the subject of the experiments reported in this paper. Imported TSP is widely used at present in Sri Lanka together with imported rock phosphate.

### **Geological and mining aspects of Eppawala Apatite**

The Eppawala rock phosphate deposit was discovered in 1971 by the Geological Survey Department of Sri Lanka. The deposit is situated in the village of Eppawala about 100 km NE of Colombo. It is found on a hillock of about 75 m local relief as a thick weathering profile developed on an apatite-rich carbonate parent rock within the Precambrian metasedimentary successions of quartzite, gneisses and migmatites, marble and charnockites. The apatite-rich carbonate rock outcrops

at points in the low-lying plain surrounding the isolated ridges of the area. The deposit has been variously described as of carbonatitic or metasedimentary origin (Jayawardena, 1976; Dahanayake and Subasinghe, 1988; Appleton, 1994). In the deposit, apatite occurs in grain sizes with maximum diameter varying from a few mm to several tens of centimeters, up to 75 cm. The apatite crystals occur in: (i) the calcitic-dolomitic carbonate matrix with accessory magnetite, fluorite, biotite, pyrite and spinel of the parent rock interbanded with gneisses and migmatite (ii) the core of diopside-scapolite dikes (iii) aluminous-ferruginous-siliceous secondary phosphate matrix.

In the mid nineteen seventies, the Sri Lankan Ministry of Plan Implementation under the DDC (District Development Council) programme, began mining the deposit in mid seventies for use as a direct application fertilizer for tea, rubber and coconut. In 1979, mining was done by the Sri Lanka State Mining and Mineral Development Corporation under the Ministry of Industries. Since July 1992, mining operations are undertaken by Lanka Phosphate Limited since July 1992. The main function of these operations is to produce a product with a  $P_2O_5$  content of about 30% which is ground to *ca.* 100 mesh size B.S. This fertilizer is known as Eppawala Rock Phosphate (ERP). The ore body is bulldozed and the material is made to a size less than 1 inch by a jaw crusher. The material is then treated by ball and roller mills to produce the commercially available product. About 3000 MT of ore is mined monthly with an annual output of 35000 MT in 1992 (Sri Lanka Fertilizer Review, 1992). ERP comprises of at least two components- one relatively more soluble than the other and mineralogically and chemically different. They are the primary apatite crystals and the ferruginous-siliceous secondary phosphate matrix, respectively.

### **Mineralogy, geochemistry and solubility of Eppawala Phosphate**

At the Eppawala phosphate deposit, tropical weathering processes acting on the parent carbonate rocks and associated gneisses and migmatite have given rise to thick non-carbonate and phosphate-rich weathering profile. This profile is mined to exploit its phosphate ore. It has two dominant minable components that can be recognized with the naked eye: (i) greenish primary apatite crystals (SERP described above) and (ii)

Table 1. Chemical Analysis of primary apatite crystals (SERP), secondary apatite and matrix from Eppawala

Eppawala	E4 Primary ap. Eppawala	E3 Secondary ap. Eppawala	E1 Matrix
TP <sub>2</sub> O <sub>5</sub>	40.53	35.80	33.24
CaO (%)	54.49	49.34	43.89
F (%)	2.03	3.72	2.07
SiO <sub>2</sub> (%)	0.18	0.35	0.15
Al <sub>2</sub> O <sub>3</sub> (%)	0.04	2.51	1.45
Fe <sub>2</sub> O <sub>3</sub> (%)	0.31	3.34	11.94
Na <sub>2</sub> O (%)	0.13	0.08	0.20
K <sub>2</sub> O (%)	0.01	0.02	0.01
MgO (%)	0.10	0.07	0.18
Cl (%)	1.86	0.24	1.12
TS (%)	0.27	0.20	0.20
MnO (%)	0.02	0.18	0.23
TiO <sub>2</sub> (%)	<0.01	0.24	1.03
Org.C (%)	0.02	0.03	0.15
CO <sub>2</sub> (%)	0.54	2.09	0.78
Free H <sub>2</sub> O (%)*	0.02	0.10	0.17
LOI (%)	0.58	3.34	3.54
CaO/P <sub>2</sub> O <sub>5</sub>	1.34	1.37	1.32
(Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub> )%=R <sub>2</sub> O <sub>3</sub> %	0.35	5.85	13.39
P <sub>2</sub> O <sub>3</sub> +MgO/P <sub>2</sub> O <sub>5</sub>	0.40	0.16	0.01

TS - Total sulphur.

LOI - Loss on ignition

\* Chemical Analysis by International Fertilizer Development Centre, Alabama, USA.

brownish aluminous-ferruginous-siliceous secondary phosphate matrix.

The primary apatite grains with good crystal outlines and a large range in sizes can be separated from their loose unconsolidated matrices and can be hand-picked or mechanically separated on a large scale. X-ray diffractometry reveals the presence of hydroxyl chlorapatite with unit cell *a* dimensions ranging from 9.46 Å to 9.80 Å. Fluorapatite or francolite (carbonate apatite with unit cell *a* values from 9.353 Å to 9.370 Å), which is a more soluble variety resulting from weathering, is also found within and around the primary apatite crystals. The primary crystals have P<sub>2</sub>O<sub>5</sub> contents varying from 35 to 42%. They show 2% citric acid solubilities varying from 5.3 to 5.8% P<sub>2</sub>O<sub>5</sub>. Neutral Ammonium Citrate (NAC) solubilities vary from 2.2 to 2.7% P<sub>2</sub>O<sub>5</sub>. These are comparable to the francolite with low carbonate substitution and thus the primary apatite crystals (i.e SERP) should be more suitable for direct application than the secondary phosphate matrix

with NAC solubilities less than 2. The SERP crystals have low R<sub>2</sub>O<sub>3</sub> values ranging from 0.35 to about 1% (Dahanayake and Subasinghe, 1991; see Table 1). High Cl contents (1.8%) are the only drawback for acidulation processes. Laboratory beneficiation studies using mechanical analysis of randomly selected phosphate ore from Eppawala, show that it contains upto 70% primary apatite crystals and include small to large crystals as described above (Dahanayake, 1994).

The aluminous-ferruginous-siliceous secondary phosphate matrix is essentially a loose or partially indurated fine-grained groundmass with disseminated smaller primary apatite grains. The loose entities are more phosphatic whereas the indurated zones are ferruginous/lateritic in composition. The apatite grains have undergone various stages of transformation to secondary francolite by a process of grain diminution within and around them (Dahanayake and Subasinghe, 1990). The ultimate stage of such transformation is a crumbling mass of secondary apatite (see Table 1)

Table 2. Rice grain yield and P-enrichment in soil (greenhouse experiment)

Treatment	Reddish Brown Earth (RBE) pH = 5.8 Mahalluppallama		Red Yellow Podzolic (RYP) pH = 3.97 Makandura		Histosol pH = 3.76 Bomuwela	
	Yield (g/pot)	P (ppm)	Yield (g/pot)	P (ppm)	Yield (g/pot)	P (ppm)
	Control	46.46	4.36	42.00	8.21	13.14
TSP (25 kg/ha)	64.64	6.87	50.75	11.67	–	–
TSP (30 kg/ha)	–	–	–	–	18.15	3.91
SERP (25 kg/ha)	57.24	7.8	42.47	8.8	–	–
SERP (30 kg/ha)	–	–	–	–	16.37	2.85
SERP (50 kg/ha)	59.51	8.9	45.15	10.38	–	–

(francolite) that will nourish the fine-grained groundmass with more soluble phosphate. The matrix is dominantly formed of fluorapatite with accessory hydroxyl apatite. Crandallite, goethite, hematite, ilmenite, laterite and quartz are present in appreciable quantities. The  $P_2O_5$  content can vary from 0 to 36% in the matrix. The 2% citric acid solubility is low and can vary from 3.5 to 4.75%  $P_2O_5$  (Dahanayake and Subasinghe, 1991). The matrix has high  $R_2O_3$  contents and can be as high as 30% thus rendering this segment of Eppawala phosphate ore unsuitable for acidulation. The matrix could vary from about 30 to 60% depending on the location of the deposit. The matrix in ground form is brownish in colour and resembles the commercially available Eppawala Rock Phosphate (ERP) though slightly high in  $P_2O_5$  content at points. ERP gives NAC solubilities of less than 2 (Riggs and Syers, 1991).

Table 1 summarizes the chemistry and solubility of the three types of ore presently minable at Eppawala.

#### Agronomic potential of primary apatite as a fertilizer for rice

SERP was compared with ERP and TSP as a fertilizer in finely ground form (100 mesh) in the greenhouse and field experiments reported here. Finely ground (100 mesh) SERP and ERP were used. The experiments were carried out with selected soils and rice varieties.

Lowland soils were used in the greenhouse experiments. They were RBE (Reddish Brown Earth) from

Mahalluppallama (North Central Sri Lanka), RYP (Red Yellow Podzolic) from Makandura (North Western Sri Lanka) and half bog soil (Histosol) from Bomuwela (Western Sri Lanka). Rice plants (*Oryza sativa*, L-variety BG-94-1) were grown in 7 kg of soil (air dry basis) in pots. The treatments were: control (no P), SERP, 2SERP and TSP in RBE and RYP soils. In the case of the Histosol, only one level of SERP was used. All treatments were replicated four times in a randomized complete block design. The soils were submerged two weeks before transplanting rice. Demineralized water was used. Application of rock phosphate and TSP was done according to Sri Lankan Department of Agriculture recommendations (Table 2). All pots, including the control received 30 kg N/ha as urea and 20 kg  $K_2O$ /ha as potassium chloride to ensure that P was the only nutrient element limiting yield. The water level in the pots was brought to 2.5 cm above the soil surface. Eight weeks after transplanting rice, all pots received 70 kg N/ha in the form of urea applied to the soil surface.

Yield results are presented from the greenhouse experiments in Table 2. Yields were generally lower in the acid peaty soil, labelled as half bog soil. This is attributed to the direct and indirect effects of soil acidity on rice plants. TSP consistently gave significantly higher responses in all soils. Yield response for SERP was higher than that of control. However, this effect is not statistically significant at  $\alpha = 0.05$  (DMRT analysis). The grain yield in RBE soil was higher than those of other soils. ERP and SERP is about one quarter the cost of TSP is Sri Lanka Rs. 10,300 per MT and Eppawala Rock Phosphate is Sri Lanka Rs. 2530 per MT. Bicarbonate-extractable P, measured by the Olsen

Table 3a. Rice grain yield and P-enrichment in soil (field experiment)

Treatment	Reddish Brown Latosolic (RBL) pH 5.5 - Hindagala				Red Yellow Podzolic (RYP) pH 3.5 - Watagedara			
	1 <sup>st</sup> crop		2 <sup>nd</sup> crop		1 <sup>st</sup> crop		2 <sup>nd</sup> crop	
	Yield	P - ppm	Yield	P - ppm	Yield	P - ppm	Yield	P - ppm
	kg/ha	After the crop	kg/ha	After the crop	kg/ha	After the crop	kg/ha	After the crop
	Yala season	Maha season			Yala season	Maha season		
	1992 (March-June)	1992/93 (Oct-Feb)			1992 (March-June)	1992/93 (Oct-Feb)		
Control	3589	9.01	4471	10.26	910	5.82	2050	6.12
TSP (12.5 kg P/ha)	3887	11.00	4736	12.32	1249	6.21	2330	6.8
SERP (12.5 kg P/ha)	3745	10.30	5247	13.61	1249	6.82	2450	12.6
TSP (25 kg P/ha)	4166	12.12	4562	15.23	1537	9.12	2800	8.26
SERP (25 kg P/ha)	3776	11.23	5337	28.16	1206	8.31	3590	20.03

Table 3b. Rice grain yield\* (kg/ha) response to different P-fertilizers

Treatment	RBL	RYP
Control	4471.9 <sup>b</sup>	2050.6 <sup>b</sup>
TSP	4649.4 <sup>b</sup>	2565.3 <sup>b</sup>
SERP	5292.5 <sup>a</sup>	3020.2 <sup>a</sup>

\*Figures in the same column followed by the same letter are not significantly different at  $\alpha = 0.05$ , DMRT analysis.

*et al.*, (1954) method, was significantly higher in soils where SERP was used.

Field experiments were carried out in paddy lands belonging to the local farmers and underlain by acid soils. These were (i) Reddish Brown Latosolic (RBL) of pH 5.5 at Hindagala in the midland region of Sri Lanka and (ii) Red Yellow Podzolic (RYP) of pH 3.5 at Watagedera near Matara in the lowland region of Sri Lanka. The rice variety BG-94-1 was grown at both sites. Two levels of P, 12.5 and 25 kg P/ha and two sources of Phosphate- TSP and SERP, were used. A nil-P treatment (control) was also used. The experiments were laid out in a randomized complete block design replicated four times. P was applied once only before the first crop and effectiveness of the residues of the P fertilizers left in the soil was measured using yields of the second crop. Nitrogen as urea and potassium as potassium chloride were applied at randomized levels (based on field studies of the Sri Lankan Department of Agriculture) to ensure that P was the only nutrient element limiting yield. Two crops of rice were grown during two seasons-(i) "Yala"-April-

September- (1992) which was relatively dry and (ii) "Maha"-October-February (1992/93) which was relatively wet. Within a season, there could be sporadic rains and the weather is not regular. During watering and flooding, particularly in the Maha season, leaching of P-nutrients could occur between different plots of the experiment. The Second crop was grown to test the response of rice to the residues of the phosphate sources (residual P). Soil samples were collected from each plot after the 1<sup>st</sup> and 2<sup>nd</sup> crops for analysis of P by the method of Olsen *et al.* (1954).

The yield results for the field experiments are shown in Table 3. In the Yala season, TSP registered the best response followed by SERP and the control. In the Maha season- residual P of SERP treatment at 25Kg P/ha gave significantly higher yields than the TSP treatments in both localities. On RBL soil, residual P from SERP at 25 kg P/ha gave a better yield response than the residual P of both TSP treatments. As shown in Table 3b, SERP-treated acid soils gave rice grain yields that are significantly higher than those from TSP-treated soil and the control plots.

The soil analysis after the 1<sup>st</sup> and 2<sup>nd</sup> crops showed that the available P had increased significantly from less than 10 ppm in the control to about 25 ppm on both RYP and RBL acid soils treated with SERP at 25 kg P/ha. The abnormally high available P values obtained with SERP are attributed to low P sorption at pH 5.5. Maximum availability of P for most agricultural crops is found in the pH range 5.5 to 7 (Tisdale and Nelson, 1975). Furthermore, the pH of the RBL soil (5.5) can further increase during the rainy Maha season providing still better conditions for higher P-availability. The high values of available P after the 2<sup>nd</sup> crop in TSP-treated plots could result from leaching of P-nutrients from other plots due to flooding subsequent to rains during the latter part of the Maha season. Such high P values may not have existed during the vegetative and reproductive stages of the rice plants during the non-rainy earlier part of the Maha season. As a consequence, low rice grain yields were obtained from the TSP-treated plots, but extractable P values were subsequently high after the second crop.

## Conclusions

We therefore conclude that SERP shows potential in both pot and field studies as an alternative to imported TSP. Further field studies are required to determine the economic levels of SERP to be applied to rice crops. This requires doing field experiments on P responsive soils and using several levels of SERP and TSP to determine how much P as SERP is required to produce the same yield as TSP.

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