Phosphorus Studies in the Lowland Rice Soils of the Mid-Country Wet Zone

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INTRODUCTION

Mid-country wet zone refers to the region which lies between 300 and 1000 metres above mean sea level and receives an annual rainfall of over 2250 mm. The districts which fall into this zone are Kandy, Kegalle and Matale. The total extent of rice lands available in these districts is around 40,000 hectares, out of which 40-50 % in the Kandy and Matale districts and over 80% in the Kegalle district are cultivated with new improved varieties.

The land forms vary from undulating, rolling, hilly, steeply dissected to mountainous. The predominant rice growing Great Soil Groups present are Red Yellow Podozolic and Reddish Brown Latosolic Soils belonging to the order Ultisol (De Alwis and Panabokke, 1972). In this region rice is grown in narrow sloping valleys as well as on terraced slopes. In recent studies three distinct rice-land types namely well drained, moderately to imperfectly drained and poorly drained, have been identified (Panabokke, 1978). The water supply for the rice lands in the valleys is from rain and from the spring flow that originates in the adjacent highland. This supply is usually sufficient for two rice crops a year.

In 1972 farmers from Kegalle district reported that plant growth in certain types of fields was extremely poor resulting in severe loss of crop. Similar complaints were subsequently received from Matale and Kandy districts. The rice plants in the affected fields were stunted, had few tillers and a poor root system. In extreme cases plants died giving the field a parched appearance. It was also reported that such conditions appear more in fields planted with new improved varieties. These fields were generally 'boggy' and referred to as "madakumbura" by the farmers. It corresponds to the poorly drained rice land type mentioned earlier (Panabokke, 1978').

Preliminary greenhouse studies at Gannoruwa followed by experiments in farmers' fields in collaboration with District Agricultural Officer, Kegalle indicated that normal plant growth occurred when affected fields were treated with concentrated superphosphate instead of the recommended rock phosphate (Annual Report, Division of Agricultural Chemistry, 1972-73).

In 1971, a very large deposit of rock phosphate was discovered at Eppawela by the Geological Survey Department and consequently information was required as to its potential as a phosphorus fertilizer for rice. Initial research data reported on the suitability of Eppawela rock phosphate for rice were not comprehensive enough to make firm conclusions (Kathirgamathiayah, Rodrigo and Nagarajah, 1973; Nagarajah, 1976; Nagarajah, Amarasiri, Jauffer and Wickremasinghe, 1978).

On account of these two problems a series of experiments were carried out from 1974 to 1978 to study the response of rice to different phosphorus fertilizers including Eppawela rock phosphate in the Kandy and Matale districts. This paper discusses the results of these investigations.

MATERIALS AND METHODS

1. *Phosphorus Fertlizers*

Six forms of phosphorus fertilizer were tested in the different experiments. They were, imported rock phosphate (IRP), Eppawela rock phosphate (ERP), fused Eppawela rock phosphate (FERP), Rhenania phosphate (RHP), fused mangesium phosphate (FMP) and concentrated superphosphate (CSP). The total, citric acid-soluble and water-soluble P_2O_5 contents of these fertilizers are given in Table 1. Some details of these fertilizers are as follows:

(*a*) Imported rock phosphate: mined apatite imported from the Middle East, especially from Egypt and Jordan.

(*b*) Eppawela rock phosphate: locally available apatite from Eppawela. An estimated quantity of about 25 million tons is available at the deposit.

(*c*) Rhenania phosphate: a product manufactured in West Germany by fusing rock phosphate with quartz and soda ash at 1100^0 C.

(*d*) Fused Eppawela rock phosphate: prepared by fusing Eppawela rock phosphate with quartz and soda ash at 1100^0 C (Rhenania process) at the Lanka Porcelain Ltd. factory in Matale (Amarasiri and Ambepitiya), 1976.

(*e*) Fused magnesium phosphate: a product manufactured in Japan by fusing rock phosphate with serpentine (a magnesium silicate) at 1400^{0}C.

(*f*) Concentrated superphosphate: a product manufactured by reacting rock phosphate with phosphoric acid.

2. *Field Experimentation*

The experiments were laid down in farmers' fields where complaints of poor plant growth were reported (exception being Kumburegama) as simple randomized complete blocks with four replicates at each location. The soil analyses of the different locations are given in Table 2.

The details of the different field experiments are as follows:

(*a*) Forms of Phosphorus Fertilizer Experiments

During maha 1975/76 and yala 1976 four forms of phosphorus fertilizer namely imported rock phosphate, Eppawela rock phosphate, Rhenania phosphate and concentrated superphosphate were tested at two levels against a no phosphorus control in a number of farmer's fields.

In maha 1976/77 fused Eppawela rock phosphate was included in place of imported rock phosphate. During maha 1977/78 and yala 1978 fused magnesium phosphate was tested in place of fused Eppawela rock phosphate at two locations, one (Nagahatenne) where phosphorus was limiting and the other (Kumburegama) where response to added phosphorus was not high.

No attempt was made to eliminate any effects on rice growth due to silicon present in Rhenania phosphate and fused magnesium phosphate and magnesium present in fused magnesium phosphate.

(*b*) Long-Term Experiments

(i) Gampolawela (Gampola)

In Maha 1974/75 four forms of phosphorus namely Eppawela rock phset phate, imported rock phosphate, Rhenania phosphate and concentraod-superphosphate were compared at two levels against a no phosphorus control. This experiment was continued in yala 1975 and maha 1975/76 at the same location by maintaining the same treatments in the same plots.

(ii) Wavekumbura (Gampola)

An experiment consisting of eight treatments (O, N, P, K, NP, PK, NK and NPK) was carried out on a phosphorus-deficient soil for four consecutive seasons commencing from yala 1976. The plots had the same treatments right throughout the four seasons. Every season phosphorus was applied as concentrated superphosphate.

(*c*) Forms of Phosphorus Fertilizer and Rice Varieties.

The performance of two rice varieties (old improved–H 4 and new improved-Bg 11-11) were tested with and without phosphorus fertilizer in two phosphorus deficient soils. Two forms of phosphorus fertilizer namely imported rock phosphate and concentrated superphosphate were also evaluated in this experiment. The locations were Thalamurayaya and Golahanwatte.

(*d*) Mixture of Water-soluble and Water-insoluble Phosphorus Fertilizers

The performance of mixtures containing different proportions of concentrated superphosphate with imported rock phosphate, Eppawela rock phosphate and fused Eppawela rock phosphate were tested in two soils during maha 1976/77. These treatments were compared with concentrated superphosphate applied at 60 kg P_2O_5/ha. Fused Eppawela rock phosphate at two rates (60 and 90 kg. P_2O_5/ha) were also tested.

Upto maha (wet season) 1975/76 the plot size was 3.05 m x 6.10 m with a spacing of 30.5 cm between rows and 15.25 cm in the rows. From yala (dry season) 1976 the plot size was 3 m x 6 m with a spacing of 20 cm between rows and 15 cm in the rows. For the long term experiment at Wavekumbura the plot size was 3 m x 5 m while the spacing was 20 cm x 20 cm.

Phosphorus fertilizer was broadcast on the soil surface and mixed into the top 5 cm of the soil just before planting. Nitrogen as urea was applied at 2, 4 and 8 weeks after transplanting for 4-4 1/2 month varieties and at 2 and 4 weeks after transplanting for 3 month varieties. Potassium in the form of muriate of potash was applied at planting and primordial initiation stage. The rates of nitrogen, phosphorus and potassium applied and varieties grown are indicated under the respective tables. For transplanting 18 to 21 day-old rice seedlings were used. The crop was protected from insect attacks by applying appropriate agrochemicals.

At maturity harvesting was carried out after discarding two rows of plants around each plot. Panicles were threshed, winnowed and paddy yield recorded at 14% moisture.

RESULTS

I. *Field Experiments*

1. Forms of Phosphorus Fertilizer Experiments

(*a*) Maha 1975/76 and Yala 1976.

There was a significant response to phosphorus at all locations when Rhenania phosphate and concentrated superphosphate were applied (Table 3). However, there were no differences between these two fertilizers. Generally Eppawela rock phosphate and imported rock phosphate failed to significantly increase the yields over the control. The higher level of Rhenania phosphate and concentrated superphosphate was significant only at Golahanwatte and Gampolawela.

(*b*) Maha 1976/77

At Wavekumbura Eppawela rock phosphate was inferior to all other forms of phosphorus fertilizer while fused Eppawela rock phosphate performed equally well as Rhenania phosphate and concentrated superphosphate (Table 4). Phosphorus content in plant samples also followed the same trends at the two locations (Table 5).

Although the grain yield data showed similar trends at Kobbekaduwa the results were not statistically significant. The second level of fused Eppawela rock phosphate and Rhenania phosphate was better than Eppawela rock phosphate. However, Eppawela rock phosphate did not give a significant response over the control.

(*c*) Maha 1977/78 and Yala 1978

At Nagahatenne fused magnesium phosphate, Rhenania phosphate and concentrated superphosphate performed equally well and were significantly better than the first level of Eppawela rock phosphate and the control (Table 6) During the maha season at Kumburegama only concentrated superphosphate gave significant response over the control. However, in yala 1978 Rhenania phosphate and concentrated superphosphate were superior to Eppawela rock phosphate and the control (Table 6).

2. *Long-Term Experiments*

(*a*) Gampolawela

The grain yield data show that in all seasons Rhenania phosphate and concentrated superphosphate were significantly better than imported rock phosphate and Eppawela rock phosphate, with imported rock phosphate giving higher yields than Eppawela rock phosphate (Table 7). In all three seasons the second level of concentrated superphosphate was superior to the first level.

The residual and cumulative effects of the different forms as measured by the increase in yield over the control showed that these effects were higher for concentrated superphosphate and Rhenania phosphate and lowest for Eppawela rock phosphate (Table 7).

(*b*) Wavekumbura (Gampola)

The grain yield data presented in Table 8 clearly show that of the three major nutrients the greatest response is for the addition of phosphorus either alone or in combinations with nitrogen and potassium. On the other hand, the grain yield for nitrogen and potassium applications declined steadily, from yala 1976 to maha 1977/78. The highest yield was consistently obtained for the NPK treatment and this was significantly superior to all other treatments. The experiment demonstrates that when P is limiting addition of N or K only (as some farmers tried and failed) cannot remedy the problem. This is more so when rice is grown continuously with addition of N and K only.

3. *Forms of Phosphorus Fertilizer and Rice Varieties*

At Thalamurayaya, with or without phosphorus the variety H 4 performed better than Bg 11-11 (Table 9). Concentrated superphosphate was far superior to rock phosphate with both varieties while there was no significant difference between rock phosphate and the control. At Golahanwatte the results were similar except that there were no significant differences between the two varieties (Table 9).

4. *Mixture of Water-soluble and Water-insoluble Phosphorus Fertilizers,*

The grain yield data presented in Table 10 indicate the following:

(*a*) At both locations responses to phosphorus fertilizers were highly significant.

(*b*) Concentrated superphosphate gave the highest yield at both locations. At Thalamurayaya it was better than all the other treatments while at Nagahatenne, fused Eppawela rock phosphate and its mixtures with concentrated superphosphate were not inferior to concentrated superphosphate alone.

(*c*) At Thalamurayaya the concentrated superphosphate mixtures with fused Eppawela rock phosphate were better than those with Eppawela rock phosphate or imported rock phosphate. However these mixtures were all inferior to concentrated superphosphate or fused Eppawela rock phosphate.

(*d*) At Nagahatenne concentrated superphosphate was not superior to fused Eppawela rock phosphate and the mixtures of concentrated superphosphate and fused Eppawela rock phosphate were as good as concentrated superphosphate. The mixtures of concentrated superphosphate and Eppawela rock phosphate (except 1/2 and 1/2) on the other hand, were inferior to concentrated superphosphate alone.

The final effect of mixtures containing rock phosphate and concentrated superphosphate on grain yield appears to be due to concentrated superphosphate and not due to rock phosphate. In other words, mixing rock phosphate with concentrated superphosphate does not improve the performance of rock phosphate.

II. *Field Observations*

In all the experiments a remarkable effect on growth of plants was observed when soluble phosphorus fertilizers were applied. Such an effect is illustrated in Figure 1 which shows the appearance of rice plants (Bg. 11-11) in a no-phosphorus plot and a concentrated superphosphate-treated plot at 24 days after transplanting. Without phosphate, plants appear stunted, with erect leaves and with few tillers.

The no-phosphorus plots or plots treated with rock phosphate flowered and matured late. In fact, in such cases the age of the plants stretched by more than 2 to 3 weeks. On the other hand, plots treated with concentrated superphosphate, flowered and matured according to the normal age of the variety. The extent to which the maturity of a variety was delayed seems to depend on the phosphorus status of the soil.

Because of this delay in maturity, the harvesting of the different treatments were staggered. Thus the concentrated superphosphate or Rhenania phospate-treated plots were harvested earlier than the no phosphorus and rock phosphate-treated plots. The difference in time generally varied from 1 to 3 weeks depending on the severity of the problem in the soil.

The delay in maturity also resulted in differential insect attack especially by that of paddy bug. Consequently the final grain yield data of many experiments were affected and their results could not be reported.

In transplanted fields the symptoms of phosphorus deficiency become apparent only when tillering commences. The plant growth however has been found to improve with time. The extent to which this improvement takes place seems to depend on the severity of the problem. In very extreme cases the plant growth does not improve at all. The plants begin to die giving the field a parched appearance. The drying starts from the tip of the leaf extending towards the base. The affected plants also have very poor root growth. Direct seeded rice crop seems to suffer more from this condition than a transplanted crop as observed in some farmers' fields in Ulapane.

In some locations (for example, Wavekumbura) non-uniform plant growth was observed in no phosphorus and Rhenania phosphate-treated plots but not in the plots treated with concentrated superphosphate.

In affected farmers' fields weed growth is abundant which is often neglected by the farmers resulting in complete loss of yield. However in experimental plots weeding and other operations are carried out in the control plots also which therefore gives reasonably high yields as indicated by the results.

DISCUSSION

1. *Response to Added Phosphorus and Soil Phosphorus Status*

Poor plant growth which is often observed in the rice fields of the mid country wet zone appears to be due to phosphorus deficiency. This is very well supported by field experiments which show that plant growth is normal in fields to which phosphorus fertilizer such as superphosphate has been added.

That phosphorus is limiting in these fields can also be seen from an examination of their total and available phosphorus status.

The amount of total phosphorus in a soil depends on its parent material. For example, high values are obtained for soils containing calcareous skeletel remains. It is also affected by the intensity of weathering–total phosphorus decreasing with increasing intensity of weathering. The total phosphorus contents of the experimental soils are around 0.05% (Table 2) and this value is very low compared to 0.3% P reported in sub-humid cool temperate regions (Pierre and Norman, 1953). On the other hand, humid warm temperate regions have values less than 0.05% while many mature upland soils of the humid tropics contain less than 0.02% (Middleton, 1954; Nye and Bertheus, 1957; Enwezor and Moore, 1966.) In the mid country wet zone where the parent material consists mainly of acid crystalline rocks and where the intensity of weathering is high, the occurrence of low total phosphorus content in many rice fields is therefore not surprising.

In most Asian countries available phosphorus determined by the Olsen method (Olsen *et al,* 1954) was found to be superior to the other methods in correlating soil phosphorus with rice response (Chang, 1965; Wang, 1965; Chang, Auerijero and Frias, 1967; IRRI, 1967; Goswami *et al,* 1971; Nambiar *et al,* 1973; Chang, 1976). Olsen method is also more universally applicable to all types of soils (Chang, 1978). Furthermore, aerobic and anaerobic phosphorus determined by the Olsen method is highly correlated regardless of the pH (Chang and Maleewan, 1972; Ekpete, 1976). Thus phosphorus status of rice soils can be easily judged by determining Olsen's phosphorus on dry samples.

Available phosphorus as determined by Olsen method is around 5.0 ppm for most of the experimental soils (Table 2) and this value is considered low (Olsen, 1954; Panabokke and Nagarajah, 1964; Patnaik, 1970). The observed grain yield response to added P in these soils is therefore to be expected.

In contrast to this, in a rice field in Gampola with high soil phosphorus (Olsen P, 10.0 ppm and Total P, 0.113%) there was no grain yield response to added P, although during initial stages, plant growth differences were observed between no-P and P-treated plots. (Yala Report, Div. of Agric. Chem., 1977).

The greenhouse data on changes in water soluble phosphorus with time of submergence given below indicate that problem soils have very low water soluble phosphorus contents compared to a normal soil.

	ppm P in water percolate					
	Days after submergence					
	4	8	15	38	72	126
(a) P-deficient soils						
Golahanwatte	0.052	0.015	0.000	0.019	0.000	0.000
Nagahatenne	0.052	0.015	0.000	0.019	0.000	0.000
Kobbekaduwa	0.031	0.000	0.000	0.019	0.000	0.000
(b) Normal soil						
Gampolawela*	0.396	0.450	0.292	0.165	0.142	0.126

* This location (Total P, 0.113 and Olsen P, 10.0 ppm) is different from the one indicated in Tables 2, 3 and 7.

Quantitative data are now available to show that in the mid country wet zone, total and available phosphorus contents of poorly drained soils are lower than neighbouring better drained fields (Maraikar, 1979).

2. *Forms of Phosphorus Fertilizer and Utilization of Eppawela Rock Phosphate*

The form of phosphorus fertilizer that needs to be applied to obtain normal plant growth should be in an available form as in concentrated superphosphate, which is water soluble or as in Rhenania phosphate and fused magnesium phosphate, which have high citric acid soluble P_2O_5 contents (and high citric acid soluble P_2O_5 to total P_2O_5 ratio). On the other hand, rock phosphates (local as well as imported), which have low citric acid soluble P_2O_5 contents (and low citric acid soluble P_2O_5 to total P_2O_5 ratio) compared to the other forms of phosphorus fertilizer tested (Table 1) are not suitable even with higher rates of application.

The long term experiment with different forms of phosphorus showed that there was hardly any residual or cumulative effect due to Eppawela rock phosphate while the imported rock phosphate was slightly better in this respect. The effects due to Rhenania phosphate and concentrated superphosphate however, were very significant.

It is believed that when rock phosphate is mixed with a more available phosphorus fertilizer such as superphosphate and applied, then the latter being readily available could provide the initial phosphorus requirement to the plants. Once the root system is well developed the plant could thereafter use the phosphorus slowly released from the rock phosphate. In fact, in Sri Lanka, mixtures containing different proportions of rock phosphate and concentrated superphosphate were recommended to rice by Joachim during the period 1950-1956 (Rodrigo, 1966). Now, Malaysia for some of its rice soils uses a mixture containing rock phosphate and concentrated superphosphate (Kanapathy, 1976). The experiments carried out in Matale using mixtures of concentrated superphosphate and rock phosphate or fused Eppawela rock phosphate however, failed to indicate the usefulness of this concept.

In upland soils, pH is considered as the most important factor affecting availability of phosphorus in rock phosphate sources (Bames and Kamprath, 1975). Factors such as soil type, transformation of phosphorus, presence of mycorrihiza and root exudates are also believed to affect solubility of rock phosphates (Juo and Kang, 1978). Investigations by Engelstad, Getsinger and Stangel (1972) seem to indicate that effectiveness of rock phosphate for lowland rice is also governed by the initial soil pH as for upland crops. That is, rock phosphates are more effective in acid soils than they are on alkaline soils. The importance of soil pH appears to exist inspite of the well-known increase in soil pH (for acid soils) that occurs after flooding. Engelstad *et al* (1972) who tested a number of different types of rock phosphate under varying soil conditions found that rock phosphates with a high degree of carbonate substitution, that is, partial replacement of the phosphate ion in the crystal lattice by carbonate ion, are more suitable for direct application to rice. On the other hand, rock phosphates which are essentially fluorapatite are not expected to be useful for direct application. Furthermore, even the carbonate substituted rock phosphates are suitable only in acid soils whose pH ranges from 4 to 5.5.

On this basis, Eppawela rock phosphate which is a fluorapatite rich in chlorine (Deans, 1975) cannot be expected to be suitable in the mid country wet zone whose soil pH values are in the range 5 to 8. This is clearly borne out by the results of the field experiments.

Summarizing, rock phosphates (both Eppawela and imported) are not suitable for direct application in the rice soils of the mid country wet zone. This is so even when they are supplied at higher rates or when they are mixed with concentrated superphosphate and applied. Eppawela rock phosphate also has very little residual or cumulative effect.

The better performance of Rhenania phosphate and fused magnesium phosphate could be partly due to the silicate present in them since silicon is known to have a favourable effect on rice growth (Ota and Kobayashi, 1953; Okuda and Takahashi, 1964; Rodrigo, 1964). Furthermore, silicate ion can indirectly enhance phosphorus availability in soil by displacing phosphate ions fixed by soil colloids (Toth, 1939; Kurtz, De Turk and Bray, 1946; Dean and Rubins, 1947). Fused magnesium phosphate, in addition to silicon contains magnesium as a nutrient element which however, has rarely been reported to be limiting in rice soils. Further studies are however necessary to determine whether the above conjectures are true or not.

It was indicated elsewhere that concentrated superphosphate, Rhenania phosphate and fused magnesium phosphate are all phosphorus fertilizers manufactured from rock phosphate. Therefore, although Eppawela rock phosphate is not suitable for direct use on rice, it can be used, if converted into either fused phosphates such as Rhenania phosphate and fused magnesium phosphate or acidulaied phosphates such as superphosphate. This is well illustrated by the fact that fused Eppawela rock phosphate prepared on a small scale according to the 'Rhenania' process compared very well with Rhenania phosphate and concentrated superphosphate (Table 4). The manufacture of fused magnesium phosphate from Eppawela rock phosphate is a distinct possibility in view of the recent discovery of serpentinite deposits in the Uda Walawe area.

3. *Performance of Old and New Improved Rice Varieties*

It is generally considered by farmers and Extension Officers that phosphorus deficiency in the mid country wet zone became apparent only after the introduction of new improved varieties and that the variety H 4 performs better under this condition. The experiment which compared Bg 11–11 with H 4 showed that with or without phosphorus, H 4, yielded more than Bg 11–11 and that both varieties respond well to the addition of concentrated superphosphate.

The ability of H 4 to tolerate phosphorus deficiency was first observed in a varietal screening test carried out on a phosphorus-deficient Luisiana Clay (IRRI, 1971). Subsequently in an alkaline phosphorus-deficient soil at Hyderabad H 4 turned out to be the most susceptible variety (Katyal, Seshu, Shastry and Freeman, 1975). Katyal *et al* attributed this behaviour of H 4 to the possible differences in the abilities of varieties to take up different types of soil phosphate.

Earlier Koyama, Chammek and Snitwongse (1973) observing differences in the performance of two varieties (Dwak Mali 3 and Muey Nawng 62 M) on a phosphorus-deficient acid sulphate soil, concluded that the differences are caused by the difference in the feeding power for soil phosphorus. The difference in feeding power between the two varieties was considered to be due to differences in interaction between plant roots and the phosphorus sources in the soil, that is, root excretion or microbiological interaction.

Varietal tolerance to phosphorus deficiency is now well established (Ikehashi and Ponnamperuma, 1978). This is also confirmed in the field varietal screening program conducted on a phosphorus-deficient rice field at Gampola (Gunawardena, 1979). The possibilities of obtaining rice varieties which are capable of growing well under low phosphorus conditions are therefore very promising.

CONCLUSIONS

Phosphorus deficiency is the main cause for the poor performance of rice in the 'boggy' fields (madakumbura) of the mid country wet zone. It can be easily corrected by the addition of about 40 to 60 kg P_2O_5/ha in the form of concentrated superphosphate. In better drained fields, phosphorus deficiency appears to be mild or latent and does not seriously affect grain yields. Further basic studies are needed to determine the causes for the poor phosphorus status of poorly drained soils.

Eppawela rock phosphate is not suitable for direct use in rice fields of the mid country wet zone. Its performance cannot be improved even by applying higher rates or by incorporating it in mixtures containing concentrated superphosphate. Eppawela rock phosphate has very little residual or cumulative effect. In effect the availability of phosphorus in Eppawela rock phosphate is extremely low. On the other hand, phosphates prepared from Eppawela rock phosphate by thermal fusion or acidulation should prove satisfactory.

ACKNOWLEDGEMENTS

The authors wish to thank Mrs. S. S. Maraikar for obtaining some of the greenhouse data and for statistical analysis. They also acknowledge the excellent assistance given by Messrs, G. Ratnayake, B. Wijayapala, S. M. Rambanda, R. A. Guneris Appuhamy and P. M. Dharmasuriya in the conduct of the field experiments. They also thank Mr. W. G. Nandasiri for typing the manuscript.

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Table 1. Chemical analysis of the different phosphorus fertilizers

Phosphorus Fertilizer	*Form*	*Total P_2O_5 %*	*Citric acid* soluble P_2O_5 %*	*Water soluble P_2O_5 %*	*Citric acid soluble P_2O_5 to total P_2O_5 ratio*
Eppawela rock phosphate (ERP)	Powder	32.8	3.4	0.006	0.10
Imported rock phosphate (IRP)	Powder	29.5	10.8	0.002	0.37
Fused Eppawela rock phosphate (FERP)	Powder	24.0	17.1	0.080	0.71
Rhenania phosphate (RHP)	Powder	27.2	26.0	0.665	0.96
Fused magnesium phosphate (FMP)	Granule	20.0	15.6	0.067	0.78
Concentrated superphosphate (CSP)	Granule	47.5	45.5	42.5	0.96

* 2 per cent solution.

Table 2—Soil analysis of surface samples (0-15 cm)

Location	*District*	*pH*	*Sand* %	*Silt* %	*Clay* %	*Texture*	*Organic*[1] *matter* %	*Total*[2] *N* %	*Total*[3] *P* %	*Olsen's* *P* *ppm*	*Exch.* *K* *me%*	*Free*[4] *Fe* %
Gampolawela	Kandy	5.1	16.1	31.3	52.6	C	4.8	0.24	0.090	6.4	0.22	4.55
Kobbekaduwa	Kandy	5.2	58.6	9.4	32.0	SCL	4.0	0.18	0.049	5.0	0.09	3.45
Kumburegama	Kandy	5.5	54.8	20.6	24.6	SCL	3.0	0.11	0.057	5.9	0.10	3.15
Wavekumbura	Kandy	5.3	49.4	14.1	36.5	SC	3.9	0.21	0.057	5.9	0.09	3.60
Golahanwatte	Matale	6.0	57.2	9.2	33.6	SCL	3.8	0.17	0.032	3.1	0.13	3.70
Nagahatenne	Matale	6.3	45.1	17.3	37.6	SC	4.4	0.22	0.050	3.1	0.11	3.80
Thalamurayaya	Matale	7.9	47.2	18.6	34.2	SCL	3.7	0.16	0.047	5.0	0.15	3.45

1 Walkley and Black method, 2 Kjeldahl method, 3 Perchloric acid method, 4 Asami and Kumada (1959)

Table 3—Grain yield response to different forms of phosphorus fertilizer during maha 1975/76 and yala 1976 (t/ha)

Treatment*	LOCATION				
	*Gampolawela***	*Kobbekaduwa***	*Golahanwatte***	*Nagahatenne***	*Thalamurayaya****
No phosphorus ...	2.94 e	3.03 c	2.17 d	3.32 c	0.99 c
ERP-1 ...	3.22 de	3.24 c	1.51 d	3.82 bc	1.54 bc
ERP-2 ...	3.29 d	3.22 c	1.48 d	3.61 c	1.73 bc
IRP-1 ...	4.43 c	3.37 bc	2.19 d	3.58 c	1.83 bc
IRP-2 ...	4.57 b	3.34 bc	1.44 d	3.74 bc	3.01 b
RHP-1 ...	4.67 b	3.58 abc	4.29 b	5.00 a	6.39 a
RHP-2 ...	4.93 a	4.20 a	5.17 a	4.99 a	6.84 a
CSP-1 ...	4.64 b	4.05 ab	3.21 c	4.85 ab	6.64 a
CSP-2 ...	4.87 a	4.00 ab	4.19 b	5.46 a	7.24 a
C.V.% ...	2.2	13.1	15.9	14.3	25.3
Rice Variety ...	Bg 11-11	Bg 11-11	Bg 11-11	Bg 11-11	Bg 90-2

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ha as muriate of potash.
For P, Level 1=28.6 kg P_2O_5/ha; Level 2=57.2 kg P_2O_5 /ha

** maha 1975/76 *** yala 1976
In each column, any two means followed by the same letter are not significantly different at the 5% level.

Table 4—Grain yield response to different forms of phosphorus fertilizer during maha 1976/77 (t/ha)

Treatment *	*LOCATION* Kobbekaduwa	Wavekumbura
No phosphorus	3.76 c	2.99 d
ERP-1	4.32 bc	3.67 c
ERP-2	4.44 bc	3.76 c
FERP-1	4.71 ab	4.70 bc
FERP-2	5.30 a	5.56 ab
RHP-1	4.88 ab	5.28 ab
RHP-2	5.21 a	5.91 a
CSP-1	4.93 ab	5.19 ab
CSP-2	4.75 ab	5.44 ab
C. V.%	9.2	15.0
Rice Variety	Bg 90-2	Bg 90-2

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ha as muriate of potash. For P, Level 1=40 kg P_2O_5/ha., Level 2=80 kg P_2O_5/ha.

In each column, any two means followed by the same letter are not significantly different at the 5% level.

Table 5—Phosphorus content in plant samples*-maha 1976/77

Treatment **	%P *Kobbekaduwa* 58 DAT ***		*Wavekumbura* 65 DAT ***	
No phosphorus	0.137		0.102	
ERP-1	0.165	0.157	0.100	0.099
ERP-2	0.150		0.098	
FERP-1	0.180	0.187	0.130	0.132
FERP-2	0.195		0.135	
RHP-1	0.205	0.213	0.125	0.137
RHP-2	0.222		0.150	
CSP-1	0.205	0.226	0.138	0.154
CSP-2	0.248		0.170	

* Plants were cut 2 cm above water level

** See foot note Table 4. *** DAT-Days after transplanting

Table 6—Grain yield response to different forms of phosphorus fertilizer during maha 1977/78 and yala 1978 (t/ha)

Treatment *	*Kumburegama*		*Nagahatenne*	
	maha 77/78	*yala* 78	*maha* 77/78	*yala* 78
No phosphorus	4.61 c	5.20 f	3.91 b	4.28 b
ERP-1	4.67 bc	5.41 ef	3.90 b	4.75 b
ERP-2	4.67 bc	5.46 def	4.24 a	4.95 ab
FMP-1	4.83 abc	5.96 cde	5.12 a	5.57 a
FMP-2	5.12 abc	6.08 bcd	5.79 a	5.55 a
RHP-1	4.93 abc	6.14 bc	5.61 a	5.89 a
RHP-2	5.22 abc	6.18 bc	5.85 a	5.63 a
CSP-1	5.52 ab	6.52 ab	5.90 a	5.80 a
CSP-2	5.58 a	6.87 a	5.92 a	5.63 a
C.V. %	10.2	5.3	11.2	11.1
Rice Variety	Bg 11-11	Bg 90-2	Bg 11-11	Bg 11-11

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ ha as muriate of potash.
For P, Level 1=40 kg P_2O_5 /ha, Level 2=80 kg P_2O_5 /ha.
In each column, any two means followed by the same letter are not significantly different at 5% level.

Table 7—Residual and cumulative effects of the different forms of phosphorus fertilizer at Gampolawela

Treatment *	Grain Yield (t/ha) *maha* 1974/75	*yala* 1975	*maha* 1975/76	*Yield increase for 3 seasons*
No phosphorus	2.85 e	4.25 e	2.94 e	
ERP–1	3.12 d (0.27)	4.50 d (0.25)	3.22 de (0.28)	0.80
ERP–2	3.08 d (0.23)	4.50 d (0.25)	3.29 d (0.35)	0.83
IRP–1	3.28 d (0.43)	4.64 cd (0.39)	4.43 c (1.49)	2.31
IRP–2	3.65 c (0.80)	4.76 c (0.51)	4.57 b (1.63)	2.94
RHP–1	3.77 bc (0.92)	5.00 b (0.75)	4.67 b (1.73)	3.40
RHP–2	3.95 ab (1.10)	5.15 b (0.90)	4.93 a (1.99)	3.99
CSP–1	3.72 bc (0.87)	5.15 b (0.90)	4.64 b (1.70)	3.47
CSP–2	4.17 a (1.32)	5.36 a (1.11)	4.87 a (1.93)	4.36
C.V. %	4.5	2.8	2.2	
Rice Variety	Bg 11–11	Bg 11–11	Bg 11–11	

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ha as muriate of potash.
For P, Level 1–28.6 kg. P_2O_5/ha, Level 2=57.2 kg P_2O_5/ha.
Figures within brackets indicate the yield increase over the no phosphorus treatment in t/ha.
In each column, any two means followed by the same letter are not significantly different at the 5% level.

Table 8—Response of rice to N, P and K and their combinations in a long-term experiment at Wavekumbura (Gampola)

Treatment *	Grain Yield (t/ha) *yala* 1976	*maha* 1976/77	*yala* 1977	*maha* 1977/78
No fertilizer	3.77 d	2.97 e	2.68 e	2.44 d
N	4.62 c	3.85 d	3.27 d	2.47 d
P	4.87 b	4.98 c	4.17 c	4.41 c
K	4.45 c	3.99 d	3.32 d	2.17 d
NP	5.00 b	5.83 b	4.88 b	4.93 bc
PK	4.94 b	5.75 b	5.08 b	5.41 b
NK	4.52 c	4.24 d	3.64 d	2.12 d
NPK	5.49 a	6.53 a	5.73 a	6.09 a
C. V. %	5.9	8.3	7.5	10.7
Rice Variety	Bg 11–11	Bg 90–2	Bg 90–2	Bg 90–2

* N=90 kg N/ha as urea, P=40 kg P_2O_5/ha as concentrated superphosphate, K=40 kg K_2O_5/ha as muriate of potash.
In each column, any two means followed by the same letter are not significantly different at the 5% level.

Table 9—Response of rice varieties H4 and Bg 11-11 to different forms of phosphorus fertilizer during maha 1976/77

Treatment *	*Grain Yield (t/ha)* *Golahanwatte*	*Thalamurayaya*
H 4–No phosphorus	3.94 b	3.97 c
H 4–IRP	4.20 b	4.13 c
H 4–CSP	6.95 a	5.68 a
Bg 11–11–No phosphorus	3,38 b	2.94 d
Bg 11–11–IRP	3.44 b	3.28 d
Bg 11–11–CSP	6.27 a	4.87 b
C. V. %	18.5	11.3

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ha as muriate of potash. Phosphorus treatments received 60 kg P_2O_5/ha. In each column, any two means followed by the same letter are not significantly different at the 5 % level.

Table 10—Performance of mixtures containing concentrated superphosphate and other forms of phosphorus fertilizer in different proportions (maha 1976/77)

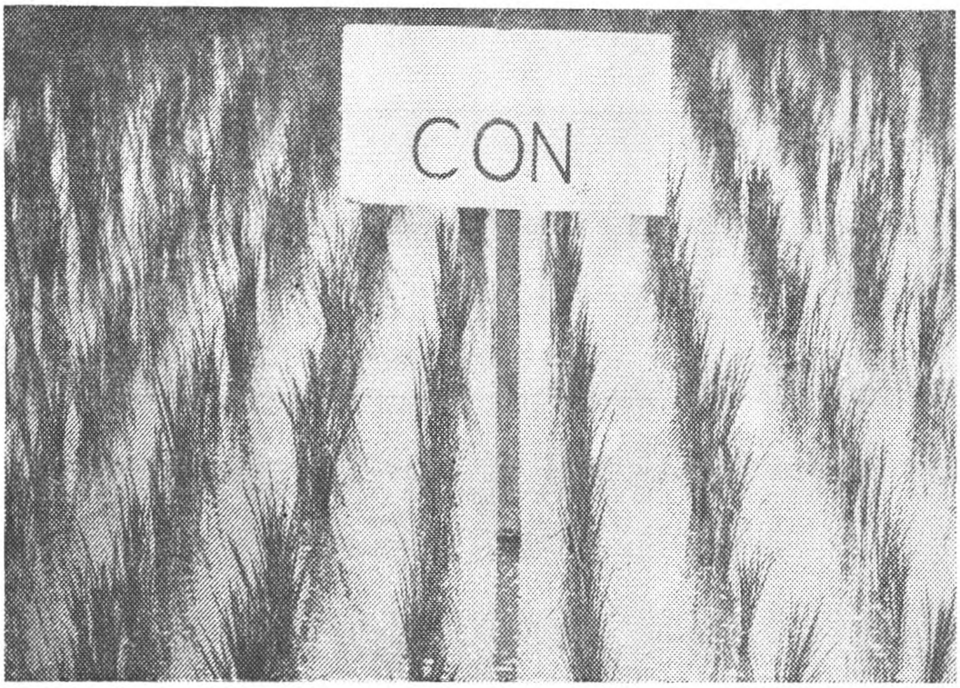
Treatment *	*Grain Yield (t/ha)* *Nagahatenne*	*Thalamurayaya*
No phosphorus	2.77 c	3.78 g
CSP 60	6,29 a	6.22 a
FERP 60	5.69 ab	5.71 b
FERP 90	5.86 ab	5.61 bc
(1/4 CSP + 3/4 FERP) 60**	5.62 ab	5.16 de
(1/2 CSP + 1/2 FERP) 60	5.88 ab	5.33 cd
(1/4 CSP + 3/4 ERP) 60	4.60 bc	4.76 f
(1/2 CSP + 1/2 ERP) 60	5.19 ab	4.85 f
(1/4 CSP + 3/4 IRP) 60	4.58 bc	4.81 f
(1/2 CSP + 1/2 IRP) 60	4.78 b	4.91 ef
C. V. %	16.2	4.0
Rice Variety	Bg 11–11	Bg 11–11

* All treatments received 81.8 kg N/ha as urea and 38.4 kg K_2O/ha as muriate of potash.

** A total of 60 kg P_2O_5/ha was applied in the form of a mixture containing 1/4 CSP and 3/4 FERP.

In each column, any two means followed by the same letter are not significantly different at the 5% level.

Figure I. Effect of phosphorus application on growth of rice at Nagahatenne (Variety: Bg 11—11 at 24 days of transplanting).



(a) Without pnosphorus

(b) With concentrated superphosphate at 80 kg P_2O_5/ha