Phosphate rock with farmyard manure as P fertilizer in neutral and weakly alkaline soils

Several scientists the world over have been trying to develop[1,2] low-cost phosphatic fertilizers. Indian scientists were successful in testing low-grade phosphate rocks[3–5] for direct application. These rocks are specified as follows: P_2O_5 content minimum 18% and in 100 mesh size. PPCL developed Mussorie Phos and M/s Rajasthan State Mines and Minerals Limited (RSMML) introduced Raj Phos conforming to these specifications. Both these products (and similar products[6] elsewhere) are successful only in acidic soils. Several attempts were made[4] to partially acidulate low-grade phosphate rocks (either with H_2SO_4 or H_3PO_4 acid) for use in neutral and alkaline soils with no success at all. These rocks were also tried along with farmyard manure (FYM) and the results were not encouraging[2–4].

Phosphorus is taken up by plants in water-soluble form as $H_2PO_4^-$, HPO_4^{--} and PO_4^{---}. Plants exude organic acids like citric and malic acids through their roots which dissolve some soil phosphates, which in turn are taken up by plants through their roots. Phosphatic fertilizers are manufactured[7] such that they contain P in water-soluble form, e.g. DAP, MAP, SSP, TSP and other nitro phosphates. However, phosphates that are soluble in citric acid or in neutral-ammonium citrate are also used as fertilizers, for plants can take up P from these forms also. Examples[7] are dicalcium phosphate and fused Ca–Mg phosphate. Water-soluble and citrate-soluble phosphates are also known as available phosphates. It is interesting to note[8] that a few days after application, soils fix water-soluble P of the fertilizer into water-insoluble forms. Fe, Al and Mn ions of the soil are responsible for fixing phosphate ions in acid soils, whereas Ca and Mg ions are responsible for the same in alkaline soils. Freshly precipitated phosphate salts of these ions (in the soil) are slowly available to the plants and upon aging, availability of P is further reduced. It is noted[8] that the most favourable pH of the soil where phosphate availability is high is somewhere between 5.5 and 7.0 and the available phosphate increases as the soil organic matter increases. It is also known[1,8] that acidic soils are limed to adjust the pH of the soil and alkaline/saline soils are conditioned with pyrite, gypsum, etc.

The important question now is, if the availability of P to the plants is dependent on the pH/organic matter of the soil and not on the form (of fertilizer) in which it is added, then why (are there) costly fertilizers like MAP and DAP? Particularly when the plants have the inherent capacity to take up soil phosphate by natural processes.

Soil phosphate solubility increases[8] as the content of organic matter in the soil increases. Presumably, while decomposing organic matter releases humic acid, which in turn convert unavailable soil phosphates into available forms. Such being the case, FYM or other organic manure if applied with high-grade phosphate minerals must work as very effective phosphate fertilizers. We proposed high-grade phosphate minerals because in the low-grade rocks, the presence of carbonate gangue minerals (calcite/dolomite in case of MRP and dolomite in case of Raj Phos) will neutralize whatsoever acidity has been generated by FYM/organic manure. It is reported[9] that one tonne of FYM and compost, on an average, contains 50–100 kg N, 50 kg P_2O_5 and 20 kg K_2O.

In the case of high-grade phosphate minerals that do not have carbonate gangue, the acidity generated by FYM/organic manure will help in bringing phosphate into available forms. This technique will be useful in neutral/alkaline soils. The techniques of using phosphate rock with organic manure (from various sources of organic matter) may be termed as PROM techniques.

The authors propose to clearly distinguish chemical and mineral fertilizers. While diammonium phosphate, monoammonium phosphate, single super phosphate, triple super phosphate and urea are chemical fertilizers, rock phosphate (directly mined or beneficiated), elemental sulphur, muriate of potash, etc. are mineral fertilizers. Scientists have been using various grades (from 18% P_2O_5 to 30% P_2O_5) of phosphate rocks of different sizes (100 to 150 microns) and they use a loose term PR to describe the material. Alternatively, we propose to use PR (34/74) for phosphate rock analysing 34% P_2O_5 and 90% of the particles being finer than 74 microns. Accordingly rocks that are already being used in acidic soils can be described as PR (18/150), meaning that the phosphate rock is having 18% P_2O_5 and 90% of the particles are finer than 150 microns.

Studies were carried out to evaluate agronomic effectiveness of high-grade rock phosphate (P_2O_5: + 34%, MgO: 2.5%, R_2O_3: 1%, LOI: 5–6%, F: 3.1% and CaO: 51%) on the yield responses of two crops, namely wheat and gram (chickpea). Mineralogically the material is pre-dominantly fluorapatite followed by some carbonate fluorapatite and chlorapatite. Minor minerals are oligoclase, sillimanite, quartz, etc. The material is 90–99% less than 74 microns and 85–95% less than 44 microns in size.

Preliminary field experiments were performed with chickpea (*Cicer arietinum* L.) at Department of Botany, Mohanlal Sukhadia University, Udaipur (soil pH ≈ 7.6), and with wheat (*Triticum aestivum* L.) at village 3 M.K., District Sri Ganganagar, Rajasthan (soil pH ≈ 8.3) during the winter season (October–April) of 1999–2000. The land at both the places was prepared by giving necessary agricultural operations like irrigation, ploughing and levelling. The experimental plots (each 1×1 m^2 and 5×25 m^2 at Udaipur and Sri Ganganagar, respectively) were replicated thrice and arranged in a randomized block design. Phosphorus as DAP and high-grade phosphate rock (PR(34/74)) was applied at the rate of 40 kg P_2O_5 ha^{-1} to each respective plot. The treatments consisted of 3 levels FYM @ 1, 2 and 4 tonnes ha^{-1} applied with PR(34/74). At Sri Ganganagar, FYM was applied only @ 4 tonnes ha^{-1} with PR(34/74). Plots were maintained weed-free throughout the plant growth. At maturity of the crop after harvesting, the biomass (aerial part, i.e. shoot + grains) was dried in the sun to a constant weight and its yield in each plot was recorded. Dried plant material will be further analysed for its nitrogen and phosphorus contents.

The results are presented in Tables 1 and 2. The results indicate that PR(34/74) + FYM combination at all levels resulted in an enhancement in both grains as well as stover yield over the controls. PR(34/74) + FYM @ 4 tonnes ha^{-1} combination proved to be even superior to DAP treatment in terms of stover as well as grain production (Table 1). Similarly, in the case of wheat, the highest straw yield was obtained in PR(34/74) + FYM @ 4 tonnes ha^{-1} combination treatment. However, PR(34/74) + FYM @ 4 tonnes ha^{-1} combination treatment also showed a remarkable enhancement in grain yield (16.32%) over the controls. The percentage increase in the grain yield in respect of DAP was 18.36, marginally higher than PR(34/74) + FYM combination. This difference, however, may be statistically insignificant. Also, the difference in the results shown in Table 1 and Table 2 is conspicuous. The pH of Ganganagar soil is higher and hence may require more FYM.

A very large volume of research work has already been carried out[2,6] on the direct application of phosphate rock as fertilizer, sometimes ending up with controversial results. For example, we find in some cases[1] that finely-ground rock phosphate was as effective as SSP, whereas in some other reports it was pointed out that MRP was effective only at 100 mesh size. In some reports it was also mentioned[2,10,11] that the performance of MRP did not improve in the presence of FYM, while in some cases MRP with FYM/organic manure was found[12] more effective. To interpret the results properly one needs complete information about the soils and about the physical/mineralogical/chemical composition of the phosphate rock being tested. Also results may vary as the crops, quality of seeds, seasons (agro-climatic conditions) and the time of application of the fertilizers change.

Soil pH between 5.5 and 7 appears most favourable for nutrient uptake by plants[8,13]. Hence while applying phosphate rock as direct P fertilizer, it is important to ensure that phosphate rock is associated with soil pH modulators like calcite or dolomite, if the soil pH is below 6, and phosphate rock should be associated with acidulating materials like organic manure, pyrite or elemental sulphur in case the soil pH is 7 or above. The use of pyrite is not recommended unless it is free from toxic heavy metals like lead, cadmium, arsenic, etc. Oxidation of elemental sulphur in the soil is not an easy task unless bacteria such as thiobaccilus thiooxidans are also used[14]. Accordingly we note that dung/FYM is the best acidulant to be used in alkaline soils as soil pH modifiers. At the cost of being repetitive the authors suggest that soil pH modification is to be aimed within the rhizosphere, i.e the phosphate rock mineral and the soil pH modulator are to be placed locally within the rhizosphere as far as possible to achieve reduced doses of FYM or other organic manure. The authors recommend only organic (FYM, weed cuttings, saw dust, crushed sugarcane, etc.) acidulants containing dung, for these materials have the capacity to reduce the toxicity of heavy metals[15,16] present in the soils. Organic manure also shows[1] buffering action.

Some scientists believe that fluorapatites are not reactive and hence do not recommend them for direct application. For example, Khasawneh and Doll[17] report that ultrafine grinding to less than 200 microns of unreactive rock could not convert it into reactive rock. It may be noted that phosphate rock used in the present work is predominantly fluorapatite and was in a much finer size (85% less than 44 microns) than 200 microns. Also we used very high-grade phosphate rock to eliminate the uncertainties caused by the gangue minerals present in the low-grade phosphate rocks. It can be seen that we did not compost (mature) phosphate rock with FYM. PR(34/74) and FYM were just mixed before application. Organic materials such as saw dust, rice husk or stalk of plants may require composting with FYM because of their slow decomposition. The concept of 'reactivity' of phosphate rocks and the necessity of composting organic matter and phosphate rock, need to be looked at afresh.

Table 1. Effect of different treatments on biomass and seed output of chickpea

Treatment condition	Biomass (g)	Seed output (g)
Soil	586	160
Only DAP	728 (+ 24.23)	258 (+ 61.25)
PR(34/74) + FYM @ 1 tonne ha^{-1}	683 (+ 16.55)	255 (+ 59.37)
PR(34/74) + FYM @ 2 tonnes ha^{-1}	752 (+ 28.32)	265 (+ 65.62)
PR(34/74) + FYM @ 4 tonnes ha^{-1}	805 (+ 37.37)	273 (+ 70.62)
FYM @ 1 tonne ha^{-1}	601 (+ 2.55)	162 (+ 1.25)
FYM @ 2 tonnes ha^{-1}	650 (+ 10.92)	190 (+ 18.752)
FYM @ 4 tonnes ha^{-1}	736 (+ 25.59)	250 (+ 56.25)

Percentage increase/decrease is given in parentheses.

Table 2. Effect of different treatments on biomass and seed output of wheat

Treatment condition	Shoot length (cm)	Biomass $plot^{-1}$ (kg)	Seed output $plot^{-1}$ (kg)
Soil	61.1	128	49
DAP	70.0 (+ 14.56)	143 (+ 11.7)	58 (+ 18.36)
Soil + FYM @ 4 tonnes ha^{-1}	70.3 (+ 15.05)	137 (+ 7.03)	50 (+ 2.04)
PR(34/74) + FYM @ 4 tonnes ha^{-1}	73.3 (+ 19.96)	149 (+ 16.40)	57 (+ 16.32)

Percentage increase/decrease is given in parentheses.

Table 3. Comparative costs of DAP and PR(34/74) + FYM per hectare

DAP	
Cost of DAP per kg, excluding the subsidy @ Rs 4 per kg	Rs 8.00
Quantity of DAP required per hectare	100 kg
Cost of DAP per hectare	Rs 800
PR(34/74)	
Cost of PR(34/74) per kg	Rs 2.34
Quantity of PR(34/74) required per hectare	132 kg
Cost of PR(34/74) per hectare	Rs 309
Cost of 4 MT of FYM @ Rs 100 per MT of FYM	Rs 400
Cost of PR(34/74) + FYM per hectare	Rs 709

It is pertinent to examine the costs involved in the technique of PR(34/74) + organic manure and DAP application. It can be seen from Table 3 that costs involved in PR(34/74) + FYM per hectare are cheaper by almost Rs 100, even if we assume a notional cost of FYM per hectare at Rs 400, which even otherwise is available to farmers. At the same time it may be remembered that the Government of India bears around Rs 1200 crores per annum as subsidy (@ Rs 4 per kg) on DAP alone. If the subsidy is removed by the government, the DAP application per hectare will be costlier by Rs 500, compared to PR(34/74) + FYM.

Phosphate rock for direct application as P fertilizer in the alkaline soils should be of high-grade (30 to 32% or + 34% P_2O_5) and very fine in size (finer than 74 microns) and should be applied @ 40 kg P_2O_5/ha (min) along with 0.5 to 4 MT/ha (max) of FYM. FYM requirement may increase if the soil pH is higher than 8. Phosphate rock and FYM should be mixed before they are locally placed. It is also known that prolonged application of chemical fertilizers destroys soil flora and fauna and thereby degrades the soils. PROM can be produced by simply mixing FYM with PR(34/74) before application or PR(34/74) may be added to dung/green leaves/weed cutting saw dust and then composted before use. Co-composting of PR(34/74) with organic matter converts a part of P_2O_5 from PR into available forms. Faster decomposition of hard cellulosic materials such as saw dust, rice husk, etc. needs further study.

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