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FINAL REPORT

FIELD EVALUATIONS OF MUSSOORIE PHOSPHATE ROCK PRODUCTS IN INDIA

for

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Introduction

During the period 1982-84, IFDC conducted a series of studies on the production of modified products from the low-grade Mussoorie phosphate rock (PR) from India. During the course of these studies, the Fertilier Technology Division of IFDC produced a wide range of materials within two general classifications: (1) partially acidulated phosphate rock (PAPR) and (2) minigranulated PR. These products were produced from both "as-received" (AR) PR and "concentrated" (C) PR. The PAPRs varied with respect to both the type of acid used (H_2SO_4 and H_3PO_4) and the degree of acidulation. The minigranulated PRs were produced with various binders, including KCl, urea, H_2SO_4, and H_3PO_4. The products and the respective process parameters are described in the Final Technology Report to UNIDO dated May 1985.

In conjunction with the production of the products described above, preliminary greenhouse and soil incubation studies were conducted to estimate their relative agronomic potential. The specific objectives of these studies were (1) to determine the agronomic potential of the minigranulated PR as compared with that of finely ground Mussoorie PR and (2) to determine the agronomic potential of PAPR as compared with that of triple superphosphate (TSP). The first objective related to technology designed to improve the physical properties of Mussoorie PR for direct application to acid soils. The second objective related to improvement of both physical and chemical properties of Mussoorie PR. On the basis of the results obtained in these studies, it was concluded that little improvement in product effectiveness could be expected through minigranulation. While results were discouraging when KCl, urea, and H_2SO_4 were used as a binder, the use of H_3PO_4 as a binder hinted that only a small increase in water-soluble P would be necessary to increase product effectiveness. The results with PAPR using either H_2SO_4 or H_3PO_4 substantiated this indication. It was concluded that PAPR showed high promise for use in India, especially with H_3PO_4. Additional detail on these studies is available in the Final Agronomic Report submitted to UNIDO in May 1985.

As a result of the findings, it was decided to select certain products from the preliminary studies for field evaluation in cropping systems typically encountered in India. Field evaluations were, therefore, initiated in the Kharif season of 1984. The findings of those field studies are contained in this report.

Objectives, Materials, and Methods

The overall objectives of the field research program remained essentially the same as those described for the preliminary greenhouse and soil incubation studies, but with the added goal of determining the stability of product performance across a range of field conditions. On the basis of the information obtained in the preliminary studies, the number of products tested was reduced to include only the most promising products for specific soil conditions. As a result, only three products were included in all thirteen of the data sets evaluated:

TSP
IFDC-702 (PAB-PAPR-50-AR)
IFDC-605 (SAB-PAPR-40-AR)

Other PAPR products studied and the number of times they were included are as follows:

IFDC-816 (PAB-PAPR-25-AR)	11
IFDC-812S (PAB-PAPR-50-C)	8
IFDC-810CS (SAB-PAPR-50-C)	5
IFDC-813S (PAB-PAPR-25-C)	4

In addition, unacidulated, finely ground Mussoorie PRs, both "as received" (MPR-AR) and "concentrated" (MPR-C), were used in a number of locations as checks on the influence of acidulation. MPR-AR was evaluated in nine data sets and MPR-C in seven data sets. A limited evaluation of minigranulation of the unacidulated PR resulted in the use of the following two products:

IFDC-301 (H_2SO_4 as binder only)	7
IFDC-400A (H_3PO_4 as binder only)	7

A summary of some of the characteristics of these products is shown in Table 1. From this summary, it can be seen that the total P_2O_5 content of the minigranulated products ranged from 16.2% to 23.9% depending on the type of binder. Those products were produced using H_2SO_4 and H_3PO_4 and compared with 18.6% P_2O_5 in the ungranulated rock. The use of H_3PO_4 as a binder increased the total P_2O_5 content to 23.9% and also increased the water- and citrate-soluble fractions above those of the other products. For the PAPRs, the use of H_2SO_4 reduced the P_2O_5 content to 14.1%-18.2%, whereas H_3PO_4 increased the grade to 26.5%-36.3% P_2O_5 because P was supplied in the acid. Water and citrate solubilities were increased significantly by the acidulation.

The experiments were conducted in collaboration with Pyrites, Phosphates, and Chemicals, Ltd., (PPCL) New Delhi, and three Indian universities. Those universities and a general description of the region in which they are situated are as follows:

1. Orissa University of Agriculture and Technology, Bhubaneswar, Orissa, India--Orissa is situated between 17°31' and 20°37' N latitude and 18°31' and 87°30' E longitude. It has an area of 155,400 km^2. The annual rainfall varies from 1,200 mm to 1,900 mm. It possesses a variety of soils from sandy loam to heavy clays. More than 50% of the cultivated land is acidic, 27% of the soils are neutral, and 5% are alkaline. The majority of the cropped area is low in organic matter, available phosphate, and available potash. The state is agriculturally suitable for the cultivation of a variety of crops--both food and commercial.

2. Birsa Agricultural Universities, Ranchi, Bihar, India--The state of Bihar, covers an area of 173,866 km^2 and stretches between 27°31' to 21°58' N latitude and 88°18' to 83°21' E longitude. The annual rainfall varies from 875 to 2,000 mm. The climate ranges from dry semihumid to humid type. The predominant soils of the region are the red loams in their characteristic reddish, reddish-yellow, or yellow color. The soils of this plateau region are poor in fertility because of large-scale soil erosion resulting in loss of fertility. These eroded soils have low base content, low cation exchange capacity (5-12 meq), and low available phosphate content (2-5 ppm); they are acidic in reaction.

3. C. S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, Bihar, India--Uttar Pradesh is one of the largest states of the country with a geological area of 294,413 km^2. The various soil types found in the state bear close relation to the climate, parent material, vegetation, and the various processes of soil formation. Of the different soil groups, alluvial soils constitute the most extensive soil formation of the state, accounting for about 61% of its total area. The climate of the alluvial region varies from

semiarid to subhumid. The rainfall varies from 700 mm to 1,100 mm. Agriculturally, the alluvial soils of Uttar Pradesh are highly productive. The soils respond very well to manuring and are highly adaptable to the cropping patterns in their various agroclimatic regions.

Experiments were established during the Kharif season of 1984. These are identified as follows:

Experiment Number	Location	Indicator Crop	P Application
PPCL-B1R-84	Bhubaneswar, Site 1	Rice	Fresh
PPCL-B2R-84	Bhubaneswar, Site 2	Rice	Fresh
PPCL-K1R-84	Kanpur, Site 1	Rice	Fresh
PPCL-R1R-84	Ranchi, Site 1	Rice	Fresh

During the subsequent Rabi season (1984/85), the above listed experimental plots were replanted and identified as follows:

Experiment Number	Location	Indicator Crop	P Application
PPCL-B1P-84	Bhubaneswar, Site 1	Pulse (green gram)	Residual
PPCL-B2P-84	Bhubaneswar, Site 2	Pulse (groundnut)	Residual
PPCL-K1W-84	Kanpur, Site 1	Wheat	Residual
PPCL-R1W-84	Ranchi, Site 1	Wheat	Reapplied

The rotations used in these four sites represent typical patterns for each of these regions. As noted above, the P treatments were reapplied prior to the second cropping period in only one of the four experiments. Continued cropping and evaluation of frequency of application is considered important because of the extended residual value of P-containing fertilizers.

In addition to the experiments listed above, two new experiments were established in the Rabi season (1984/85). They are identified as follows:

Experiment Number	Location	Indicator Crop	P Application
PPCL-B3P-84	Bhubaneswar, Site 3	Pulse (green gram)	Fresh
PPCL-K2W-84	Kanpur, Site 2	Wheat	Fresh

As can be seen, these two experiments repeat evaluation of the products with the same indicator crop grown in the same season, but with fresh application of the P treatments as a comparison against the residual plots previously identified.

Three experiments were replanted in the subsequent Kharif season of 1985.

Experiment Number	Location	Indicator Crop	P Application
PPCL-B3R-85	Bhubaneswar, Site 3	Rice	Residual
PPCL-K2R-85	Kanpur, Site 2	Rice	Residual
PPCL-R1R-85	Ranchi, Site 1	Rice	Residual

Each of these experiments measures the residual value of previously applied P with rice as the indicator crop. In Bhubaneswar the P applications were made prior to the first crop of the rotation which was green gram, while in Kanpur the first crop was wheat. The experiment in Ranchi was an evaluation of the residual P value of the products in a rice-wheat-rice rotation where P had been applied prior to both of the first two crops.

The products used in each of the experiments are summarized in Table 2, and some of the soil chemical properties of the locations as measured prior to application of any fertilizer materials are given in Table 3.

In each of the experiments, the P sources were broadcast and incorporated into the soil at three positive rates of application in an attempt to describe a complete response curve. A check treatment in which no P had been applied was also included to determine the degree to which P was a limiting factor. All treatments were replicated three times in a completely randomized block design. Applications of nitrogen and potassium were uniform within each experiment. Weed, pest, and water control was also uniform within experiments. Additional details on experimental materials are given in Table 4.

All inferences on crop response to P from the varied sources are based on grain yield of the respective crop. Soil measurements, including pH, extractable P, P sorption capacity, and extractable cations were also determined.

Results and Discussion

A number of criteria can be used to determine the relative effectiveness of a range of P-containing fertilizers. Two questions that will be addressed in this report are as follows:

1. On the assumption that the indicator crop is an extractor of available P, how do the sources compare as measured by the yield response in the first crop following application?
2. Again as in 1 above, how do the sources compare as measured by the yield response in the second crop following application without reapplication (residual value)?

These two questions can be answered only if, in fact, there was a response to P by the indicator crop.

Kharif 1984

Results from the four experiments which initiated the project in the Kharif season of 1984 show that indeed there were substantial increases in yield due to the application of the P-containing fertilizer above the yield of the check which received no additional P (Tables 5-8). With the assumption that TSP is the standard source to represent the most highly available form of fertilizer P, the determination of whether or not the response to P is significant can be made by observing the results of Duncan's multiple range test as shown on these tables. In each case, the mean yield obtained by TSP application is significantly higher than the yield of the check treatment.

In the analysis of variance (ANOVA) calculations, the check was treated as a source of P; again, this analysis showed that there were statistically significant differences among the sources tested in all trials except R1R-84, which was conducted in Ranchi. Additionally, Ranchi was the only site in which significant differences were not obtained among the various positive rates of application. The reason for this reduced level of response can be found by reexamining Tables 3 and 4. First, exchangeable Mg was found to be low in this soil and could have limited crop response. Additionally, the rates of application were lower than in the other sites, not only for the experimental P products but also for N and K. Since Table 8 shows that, compared with the other sites, crop yields were generally low, it is suggested that higher yields and a greater ability to evaluate the differences between sources would be possible with increased inputs of N, P, K, and Mg. The ANOVA procedure, however, evaluates the combined effect of all observations and, while overall there were no significant differences between sources and rates, the singular effect of TSP was significantly greater than the check (as shown by Duncan's multiple range test).

It can be concluded, therefore, that all sites can be used for source evaluations. The data in Tables 5-8 and the statistical analysis just described also show, however, that in most cases the maximum response per unit of P applied was obtained at the lower rates of application and that a response plateau was approached or reached at the higher rates of application. The yield data were used, therefore, to construct a model of the response based on a number of mathematical relationships. Comparison of these models showed that yield response to P was best described by a semilog model in the form of $y = \alpha + \beta \ln P$ where y = the predicted yield, α = the y intercept and ln P = the natural logarithm of the rate of P applied. The modeled response functions for the first four experiments are given in Tables 9-12.

While these response functions are most useful in determining whether or not there are significant differences among sources across an entire range of rates of applications, they can also be used to (1) determine the magnitude of response at a given rate of application, (2) calculate the optimum agronomic rate of application, and (3) calculate the optimum economic rate of application. When these equations are used for the first objective, for example, it can be seen that the predicted increase of yield above the check for TSP at a typical rate of application (i.e., 40 kg ha^{-1} for rice) was as follows in those four sites where rice was used as the indicator crop.

Experiment	Yield Increase at 40 kg ha^{-1}
	- - -(%) - - -
B1R-84	18.9
B2R-84	12.8
K1R-84	22.8
R1R-84	15.7

This represents an average increase in rice yield of 17.6% across the four sites due to the application of 40 kg P_2O_5 ha^{-1} of TSP, again verifying the response to applied P.

Upon further examination of the response functions, the following relationships among sources can be observed on a location-by-location basis.

Bhubaneswar--Two experiments were conducted in this region with the sites being selected on the assumption that at the second site (B2) the acidity of the soil was greater than that of the first site (B1) and would, therefore, be more appropriate for inclusion of unacidulated Mussoorie PR. Site B1, therefore, was used to test a range of six PAPR products, while at Site B2 only three PAPR products were included and four unacidulated products were added. The soil chemical data presented in Table 3, however, show that there was very little difference between the soil properties in these two sites. Both soils were at a pH of approximately 5.8 at the time of planting, and the soil at B1 was only slightly higher in extractable P and exchangeable cations. The P sorption capacity, at both sites, is considered low when compared with that of many of the acid soils in tropical regions. Also, in both sites, it can be seen from Tables 9 and 10 that the response of rice to P was greatest when the Mussoorie PR was acidulated with 50% of the H_3PO_4 required to produce TSP (IFDC-702). This response, however, was not significantly greater than that obtained with TSP and, in fact, none of the PAPR products were statistically different from the TSP. The only product that was found to be significantly less effective than TSP was the unacidulated, concentrated Mussoorie PR (MPR-C) in Site B2. Several products, however, were found to be less effective than IFDC-702, but only in Site B2.

Ranchi--As shown in Table 3 the experiment planted in Ranchi was on a soil with a pH only slightly higher than those in Bhubaneswar (approximately 6.0). It was also somewhat higher in available P but lower in exchangeable cations when compared with Bhubaneswar. The P sorption capacity at Ranchi was the highest reported, but it is still considered relatively low. In general, the yields were similar to those obtained in Bhubaneswar (Site 2). It was again observed (Table 12) that 50% H_3PO_4 PAPR was the most effective of the PAPR products (in this case IFDC-812), and that it was not significantly less effective than TSP. In this case, however, it was interesting to note that there was no significant difference among any of the products produced from Mussoorie PR (i.e., the ground, minigranulated and partially acidulated products were all similar in effectiveness). As mentioned previously, however, these observations were probably influenced by the low rates of N, P, and K applications. It is likely that an expanded response curve (i.e., 0, 40, 80, and 120, instead of 0, 20, 40, 60), in combination with a doubling of N and P application, could serve to more accurately determine the relative potential of the sources since (1) the reflection of P response would not be limited by N and K constraints and (2) differences in the shape of the response curves could more adequately be analyzed.

Kanpur--The soil at the Kanpur site was considerably different from that in the previously described locations (Table 3). It had a pH of 7.9 and considerably higher levels of exchangeable cations. The native P level was also higher and the P sorption capacity was very low. As a result, the yields were generally higher than those obtained in the other locations. These higher yields were also facilitated by higher application of N and K and the supplemental application of $ZnSO_4$ (Table 4). Nevertheless, the response of rice to applied P was also greater than in the other locations (Table 11). As in the other locations, all of the PAPR products were statistically similar to TSP and, in fact, three of them resulted in slightly greater response as compared with TSP (but not significantly). Again, the only product that was significantly lower in effectiveness was unacidulated Mussoorie PR (MPR-AR). It is of interest to note, however, that, despite the elevated pH, there was a response to P from the unacidulated PR and, in the case of MRP-C, the response was similar to that of the acidulated products.

Rabi--1984/85

As previously indicated, a complete characterization of a P fertilizer source cannot be obtained by the results of a single cropping season. To evaluate the residual availability of P from these sources, the experiments previously discussed were recropped during the 1984/85 Rabi season by following typical crop rotations in each region (Table 2). The yield results for these residual trials are presented in Tables 13-16. It can be seen from these data that, even for those experiments in which P was not reapplied, there continued to be a response to the P which was applied prior to the Kharif 1984 crop. The ANOVA calculations presented verify that the differences between P rates were, in fact, highly significant.

As with the data obtained in the Kharif 1984 season, the crop response across the entire range of application rates was best described by a semilog model in the form of $y = \alpha + \beta \ln P$. These response functions are given in Tables 17-20. When these equations are used, as before, to determine the degree of response at a given rate of 40 kg P_2O_5 ha^{-1}, it can be seen from the data below that there was an average increase in crop production of 40.3% due to the residual P from TSP.

Experiment	Crop	Yield Increase at 40 kg ha^{-1}
		- - -(%) - - -
B1P-84	Green gram	58.1
B2P-84	Groundnut	25.6
K1W-84	Wheat	37.9
R1W-84	Wheat	39.7

Two observations are highly noteworthy in the residual experiments conducted in the Rabi season: (1) the continued response to P described above and (2) the fact that there were no significant differences among any of the sources reflected in the crop yields. Any significant differences between TSP, PAPR, minigranulated PR, or finely ground PR had disappeared by the second crop. This suggests that because there was sufficient dissolution of P in all of the products, the residual P availability was being controlled by the soil reaction products rather than by the chemical properties of the fertilizer sources.

In the case of experiment R1W-84 in which P was reapplied at the initial rates of application prior to the second crop, it was observed that, in addition to rate of application, the influence of the source properties did continue to be important (Table 16). Not only were P source and P rate differences highly significant, but for the first time it was observed that there was a P source x P rate interaction. This indicates that the degree to which yield was influenced by increasing rates of application was not the same for all of the sources. Since this was also the first case where there were repeated applications of the P sources, it suggests that the additive effects from soil reaction products plus freshly dissolved products will vary depending upon source solubility. The response functions (Table 20) illustrate this relationship. It can be seen that all sources which contain a portion of the P in a water-soluble form performed significantly better than all sources that were unacidulated--usually by more than a factor of 2. This supports the theory that the P from the unacidulated PR was relatively unavailable when compared with the P in the soil reaction products from the previous application. The plant response was most likely due to residual effect with those products, whereas with the TSP and PAPR, the primary source of plant-available P was the freshly applied fertilizer.

The new experiments that were planted in the Rabi season (1984/85) were established on a third site in Bhubaneswar (B3) with green gram as the indicator crop and on a second site in Kanpur (K2) with wheat as the test crop.

In Bhubaneswar, green gram was also used as the test crop in the evaluation of residual effect on Site B1. Since the soil properties (Table 3), the test crop, and the climatic variables were similar for both experiments (B1P-84 and B3P-84), comparison of the yield data allows for evaluation of the difference between fresh and residual P availability from products present in both experiments. The results from B1P-84 (Table 13) have already been discussed, and the results from B3P-84 are presented in Table 21. The products that were repeated in both experiments include:

TSP

IFDC-702 (PAB-PAPR-50-AR)

IFDC-816 (PAB-PAPR-25-AR)

IFDC-605 (SAB-PAPR-40-AR)

Comparison of the two sets of yield data indicates that there was essentially no difference between the experiments. Salient observations include the following:

1. The yield of the check (O-P) treatments was essentially the same (B1P = 795 kg ha^{-1}; B3P = 813 kg ha^{-1}) indicating that the natural, nonexperimental conditions were in fact similar.
2. The CV for both experiments was similar (B1P = 8.7%; B3P = 8.1%) indicating that management of the experiments was uniform.
3. Sources common to both experiments performed in a similar manner in both experiments (i.e., there was no statistically significant difference between any of the P fertilizers but all were significantly superior to the check treatment).

It can be concluded from this comparison, therefore, that, for the cropping rotation of rice (Kharif, 1984) followed by green gram (Rabi 1984/85) under the conditions encountered in Bhubaneswar, the residual value of P supplied by TSP and the PAPR products was sufficient to supply the P requirements of the green gram without a reapplication of the fertilizers. It can also be seen from the response curves for the individual products (Table 22), that the unacidulated products freshly applied before the planting of green gram did not perform as well as TSP or the PAPRs. Both MPR-AR and MPR minigranulated with H_2SO_4 were significantly less effective than the acidulated products. These combined observations suggest, in fact, that the freshly applied unacidulated products were even less effective than the residual value of the acidulated products.

In Kanpur, experiment K2W-84 was established with fresh applications of the test fertilizers and wheat as the test crop. This experiment was a complement to experiment K1W-84 in which wheat was also grown as the test crop but without fresh applications of P. Experiment K1W-84 was the second crop in a rice-wheat rotation where the P was applied only prior to the planting of rice. The results of experiment K1W-84 (Table 15) have already been discussed, and the results of K2W-84 are presented in Table 23. The products that were repeated in both experiments include:

TSP

IFDC-702 (PAB-PAPR-50-AR)

IFDC-812S (PAB-PAPR-50-C)

IFDC-810CS (SAB-PAPR-50-C)

IFDC-605 (SAB-PAPR-40-AR)

Comparison of the two sets of yield data indicates that superior growth was obtained in experiment K2W-84 but that this difference was due to nonexperimental variables. This conclusion can be drawn from the fact that the yield of the check (0-P) treatment in experiment K2W-84 was higher than the check treatment in experiment K1W-84 by approximately 900 kg grain ha^{-1}. To estimate the degree of response to the various fertilizers above that obtained with the check, the response equations calculated in experiment K1W-84 (Table 19) and in experiment K2W-84 (Table 24) were used to estimate response at the point representing an application rate of 50 kg P_2O_5 ha^{-1}. The results of this comparison were as follows:

	Yield Increase Above Check at 50 kg P_2O_5 ha^{-1} ($kg\ ha^{-1}$)	
	K1W-84	K2W-84
TSP	964	816
IFDC-702	903	455
IFDC-812S	818	824
IFDC-810CS	1,105	690
IFDC-605	784	757

It can be seen that, again, response to the residual P (K1W-84) was similar to, and perhaps greater than, response to the freshly applied P. This again suggests that, as shown with the rice-green gram rotation in Bhubaneswar with a soil at pH 5.8, the residual value of P supplied by the TSP and the PAPR products prior to the first crop was sufficient for both crops in a rice-wheat rotation grown in Kanpur with a soil at pH 7.9. The common factor in all of these soils which may explain the response to residual P is a low P-sorption capacity--thus facilitating the utilization of the residual P.

An additional observation of relevance from these two experiments is that, in both cases, all of the PAPR products were statistically similar to TSP--as related to both fresh applications and residual response. Tnis is consistent with previous observations and can be considered reliable because of the fact that the coefficients of variation in all experiments were extremely low.

Kharif 1985

The final experiments to be considered in this series of investigations are trials planted during the Kharif season of 1985 with rice as the test crop. In the evaluation of the rice-green gram rotation at Site 1 in Bhubaneswar (Kharif 1984-Rabi 1984/85), it was concluded that the residual value of P supplied by TSP and PAPR products was sufficient to supply the P requirements of the second crop without reapplication of the fertilizer (page 11). At Site 3 in Bhubaneswar, the rotation was reversed (i.e., green gram-rice, Rabi 1984/85-Kharif 1985) with P applied only prior to the green gram. As seen in Tables 25 and 26, the rice yields observed in experiment PPCL-B3R-85 indicate that the same is true for the green gram-rice rotation. The analysis of variance shown in Table 25 shows that there was a continued response to P rates but that there was no significant difference between any of the P sources tested. Again, it appears that for both rotations, a single P application may be sufficient for at least two crops and that the differences between the P sources are likely to be observed only in the first crop immediately following application.

In all, there were five 2-crop rotations evaluated in this set of experiments, and the generalization just stated that a single application was sufficient for at least two crops was based on four of those five rotations. The only location in which significant response to residual P was not observed was at Site 2 in Kanpur. In that location, there was significant response to P in the first crop (wheat, Rabi 1984/85) but, as shown in Table 27, the increases in yield obtained from the residual P treatments were not significantly higher than the check treatment.

The final experiment of this season to be discussed is the one planted at Site 1 in Ranchi. This trial is the third season in a rice-wheat-rice rotation. Prior to the planting of both of the first two crops of the rotation (R1R-84 and R1W-84), the P fertilizer treatments were freshly applied. In this third crop (R1R-85), however, no additional P was applied, thus allowing for an evaluation of the combined residual effect of two previous applications. The yield results of this trial are presented in Tables 28 and 29, and it can be observed from these data that there were significant differences in yield due to both the source of P and the rate of application.

In this case, there was considerable response to the residual P up to a rate where at least 40 kg P_2O_5 ha^{-1} had twice previously been applied (total of 80 kg P_2O_5 ha^{-1}). As seen in the previous discussions, the PAB-PAPRs continued to be the most effective products, but considerable response was also observed to the unacidulated products. As shown in Table 28, the mean yields obtained with all products were significantly higher than the check yield. An observation of particular interest, however, is that the value of residual P from TSP was significantly lower than that of the PAPRs and not significantly different from that of the unacidulated products. This is the only one of the experiments in which there was a significant difference between the performance of TSP and the PAPRs.

Finally, with regard to crop yield observations, it can be noted that additional trials were conducted with these products at G. B. Pant University of Agriculture and Technology in Pantnagar, Uttar Pradesh. Two rotations were planted as follows:

Experiment Number	
PPCL-P1C-84 PPCL-P1W-84	Corn (Kharif, 1984) followed by wheat (Rabi, 1984/85)
and	
PPCL-P2W-84 PPCL-P2R-84	Wheat (Kharif, 1984) followed by corn (Rabi, 1984/85)

The soils on which these experiments were planted, however, were already high in available P, thus resulting in a lack of response to the applied P. These experiments are, therefore, not discussed, but the yield data can be reviewed in Appendix Tables A1-A4.

Soil Analysis

As indicated on page 5, soil measurements, including pH, extractable P, P sorption capacity, and extractable cations, were determined on composite samples collected from the experimental plots prior to initiation of the experiments as well as from the individual plots which were treated with the experimental fertilizers following each harvest. These samples were collected by the personnel at each of the universities collaborating in the evaluation and shipped to IFDC Headquarters in Muscle Shoals, Alabama, for analysis. This procedure was adopted so that the comparisons could be made on observations obtained by a single set of technicians using the same procedures, reagents, and equipment.

The measurements which contributed the greatest to an understanding of the stability of the test products were those obtained prior to initiation of the experimentation (Table 3). These results have already been discussed on a site-by-site basis and will be summarized in the next section.

The purpose in measuring soil properties following the harvest of the experiments was to determine if the test fertilizers influenced pH or exchangeable cations to different degrees dependent upon fertilizer composition. Statistical analysis verified that there was no statistical difference (P = 0.05) between sources with respect to pH, exchangeable Ca, exchangeable Mg, or exchangeable K measured following the cropping.

Differences in measurements of extractable P following cropping were generally consistent with yield observations, and the major differences were related to rate of application rather than fertilizer source. These measurements, therefore, were not useful in expanding upon interpretation of the yield data over this period of time. It is recommended, however, that extractable P levels continue to be monitored if the trials are continued since it can be predicted that the sources will vary in residual value and that these differences will be magnified with repeated applications over a long period of time.

Summary

The general conclusions that can be drawn from these trials are summarized as follows:

1. In all crops grown following fresh applications of fertilizer, there were no significant yield differences between TSP and PAPR produced from Mussoorie PR. This was observed on soils ranging in pH from 5.75 to 7.92, in P sorption capacity from 2.1% to 18.3%, and in extractable P from 6.14 ppm to 10.57 ppm (Bray P1) or 20.7 ppm of Olsen extractable P. With a uniform confidence measurement of P = 0.05, the results obtained with PAPR produced with 50% of the H_3PO_4 required for production of TSP tended to be more stable than those of the other PAPRs.
2. Under the same set of conditions, finely ground Mussoorie PR was found to be more variable and statistically less effective than the best fertilizer treatments in three of the four experiments where these sources were evaluated following fresh application. Only in Ranchi (pH 5.98) were the unacidulated products equally as effective as the acidulated products. As indicated on page 8, however, the rates of application were relatively low at this site.
3. In four of the five rotations where the test fertilizers were applied only prior to the first crop and the second crop was grown without reapplication, continued response was observed, and the residual availability of P was similar for all P sources, regardless of the fertilizer solubility or the soil properties. Rotations of this type were evaluated on soils with pH 5.75, 5.83, and 7.92.
4. In the one location where repeated applications of the fertilizers were evaluated (Ranchi, pH 5.98), the superiority of the acidulated products appeared to be magnified when compared to either a single fresh application or residual measurements. This suggests the need for additional long-term experimentation on the effects of repeated application of P sources varying in sclubility.
5. All soils were found to be relatively low in P sorption capacity indicating that care should be taken when comparing P fertilizer reactions with data obtained in other locations. The P sorption capacity of the soils tested, for example, is similar to that of many Alfisols of west Africa but far less than that of the Oxisols, Ultisols, or Andepts of Latin America.

Table 1. Chemical Analysis of Modified Products From Mussoorie Phosphate Rock for Field Trials in India

Sample Number	Sample Description	Total P_2O_5	W.S. P_2O_5	C.S. P_2O_5	CaO	F	SO_4	H_2O	Type Rock[a]
		(wt %)							
301	Minigranules	16.2	0.5	0.8	36.3	1.7	7.0	0.1	AR
400-A	Minigranules	23.9	1.4	6.3	39.8	1.8	-	0.3	AR
605	Granular	14.1	3.8	1.7	31.3	1.0	26.6	2.1	AR
816	Granular	26.5	3.6	8.1	33.5	1.7	-	1.4	AR
702	Granular	32.3	14.8	4.7	31.2	1.6	-	0.4	AR
810-C-S	Granular	18.2	9.0	1.0	32.3	1.1	30.7	3.3	Sala
813-S	Granular	32.8	7.8	4.2	40.0	2.3	-	0.7	Sala
812-S	Granular	36.3	20.0	1.5	33.4	1.9	-	1.5	Sala

a. AR = as-received; Sala = Sala concentrate.

Table 2. Summary of Experiments, Rotations, and P-Fertilizers Used

			702	605	816	812	810	813	400	301	MPR-AR	MPR-C
Bhubaneswar												
Site 1	PPCL-B1R-84	> Rice-green gram	√	√	√	√	√	√				
	PPCL-B1P-84/85		√	√	√	√	√	√				
Site 2	PPCL-B2R-84	> Rice-groundnut	√	√	√				√	√	√	√
	PPCL-B2P-84/85		√	√	√				√	√	√	√
Site 3	PPCL-B3P-84/85	> Green gram-rice	√	√	√				√	√	√	
	PPCL-B3R-85		√	√	√				√	√	√	
Kanpur												
Site 1	PPCL-K1R-84	> Rice-wheat	√	√	√	√	√	√			√	√
	PPCL-K1W-84/85		√	√	√	√	√	√			√	√
Site 2	PPCL-K2W-84/85	> Wheat-rice	√	√		√	√					
	PPCL-K2R-85		√	√								
Ranchi												
Site 1	PPCL-R1R-84	> Rice-wheat-rice	√	√	√	√			√	√	√	√
	PPCL-R1W-84/85		√	√	√	√			√	√	√	√
	PPCL-R1R-85		√	√	√	√			√	√	√	√

Table 3. Initial Soil Properties

	Bhubaneswar				
	Site 1	Site 2	Site 3	Kanpur	Ranchi
pH	5.75	5.83	5.77	7.92	5.98
Bray P1 (ppm P)	8.81	6.14	10.57	20.70[a]	10.55
P sorption capacity (%)	14.6	12.9	7.7	2.1	18.3
Exchangeable Ca (meq/100 g)	4.35	3.81	3.87	4.42	3.47
Exchangeable Mg (meq/100 g)	1.27	1.19	1.07	2.80	0.71
Exchangeable K (meq/100 g)	0.21	0.16	0.14	0.17	0.16

a. Olsen P.

Table 4. Summary of Experimental Inputs

	Bhubaneswar	Kanpur	Ranchi
Rate of P applied (kg ha^{-1})	0, 40, 80, 120	0, 30, 60, 90	0, 20, 40, 60
Indicator crops			
1. Rice (Oriza sativa)	Var. Pratap	Var. Pratap	Var. BR-27-19
a. N applied (kg ha^{-1})	75	120	40
b. K applied (kg ha^{-1})	30	60	20
c. Zn applied (kg ha^{-1})	-	3.3	-
2. Green gram (Phaseolus aureus) and groundnut (Arachis hypogaea)	Var. HY 12-4		
a. N applied (kg ha^{-1})	20		
b. K applied (kg ha^{-1})	20		
3. Wheat (Triticum acetivum)		Var. RR-21	Var. BR-21
a. N applied (kg ha^{-1})		120	100
b. K applied (kg ha^{-1})		60	40

Table 5. Orissa University of Agriculture and Technology, Experiment PPCL-B1R-84 (Kharif 1984, Paddy Rice), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application				Mean[a]
	0	40	80	120	
	(kg P_2O_5 ha^{-1})				
Check	3,183				3,183 b
TSP		3,872	3,855	3,767	3,831 a
PAB-PAPR-50-AR (IFDC-702)		3,878	3,933	4,161	3,991 a
PAB-PAPR-50-C (IFDC-812S)		3,867	3,833	3,928	3,876 a
PAB-PAPR-25-AR (IFDC-816)		3,667	3,866	3,894	3,809 a
PAB-PAPR-25-C (IFDC-813S)		3,631	3,839	3,828	3,766 a
SAB-PAPR-50-C (IFDC-810CS)		3,650	3,933	4,061	3,881 a
SAB-PAPR-40-AR (IFDC-605)		3,578	3,955	4,234	3,922 a
Mean	3,183	3,735	3,888	3,982	3,837

Source	df	F Value
Replication	2	1.81 NS
P source	7	3.06**
P rate	2	5.37**
P source x P rate	12	0.83 NS
Error	42	
Total	65	CV = 6.4%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 6. Orissa University of Agriculture and Technology, Experiment PPCL-B2R-S4 (Kharif 1984, Rice), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	40	80	120	Mean[a]
	(kg P_2O_5 ha^{-1})				
Check	2,675				2,675 c
TSP		3,064	2,978	2,865	2,969 ab
PAB-PAPR-50-AR (IFDC-702)		3,017	3,158	3.227	3,134 a
PAB-PAPR-25-AR (IFDC-816)		2,811	2,947	2,929	2,899 bc
SAB-PAPR-40-AR (IFDC-605)		2,650	2,874	2,880	2,801 bc
Minigranulated-H_3PO_4 (IFDC-400A)		2,742	2,894	2,886	2,841 bc
Minigranulated-H_2SO_4 (IFDC-301)		2,958	2,822	3,033	2,938 ab
Mussoorie PR-AR		2,622	2,828	2,989	2,813 bc
Mussoorie PR-Conc.		2,450	2,683	2,923	2,685 c
Mean	2,675	2,789	2,898	2,968	2,833

Source	df	F Value
Replication	2	4.14*
P source	8	4.31**
P rate	2	5.32**
P source x P rate	14	1.04 NS
Error	48	
Total	74	CV = 6.6%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 7. C. B. Azad University of Agriculture and Technology, Experiment PPCL-K1R-84 (Kharif 1984, Rice), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	30	60	90	Mean[a]
	- - - - - - -(kg P_2O_5 ha^{-1}) - - - - - -				
Check	4,330				4,330 c
TSP		4,663	5,024	5,303	4,997 ab
PAB-PAPR-50-AR (IFDC-702)		4,553	4,838	5,026	4,806 ab
PAB-PAPR-50-C (IFDC-812S)		4,905	5,178	5,201	5,095 a
PAB-PAPR-25-AR (IFDC-816)		4,548	4,746	4,875	4,723 abc
PAB-PAPR-25-C (IFDC-813S)		4,631	5,339	5,129	5,033 ab
SAB-PAPR-50-C (IFDC-810CS)		4,767	5,078	5,192	5,012 ab
SAB-PAPR-40-AR (IFDC-605)		4,590	5,194	5,306	5,030 ab
Mussoorie PR-AR		4,442	4,569	4,819	4,610 bc
Mussoorie PR-Conc.		4,515	4,749	5,165	4,810 ab
Mean	4,330	4,624	4,968	5,113	4,759

Source	df	F Value
Replication	2	1.13 NS
P source	9	2.22*
P rate	2	11.39**
P source x P rate	16	0.30 NS
Error	54	
Total	83	CV = 7.9%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 8. Birsa Agricultural University, Experiment PPCL-R1R-84 (Kharif 1984, Rice), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	20	40	60	Mean[a]
	- - - - - - - (kg P_2O_5 ha^{-1}) - - - - -				
Check	2,450				2,450 b
TSP		2,700	3,100	2,983	2,928 a
FAB-PAPR-50-AR (IFDC-702)		2,600	2,667	2,483	2,583 ab
PAB-PAPR-50-C (IFDC-812S)		3,133	2,400	2,900	2,811 a
PAB-PAPR-25-AR (IFDC-816)		2,767	2,483	2,717	2,655 ab
SAB-PAPR-40-AR (IFDC-605)		2,733	2,583	2,550	2,622 ab
Minigranulated-H_3PO_4 (IFDC-400A)		2,867	2,550	2,450	2,622 ab
Minigranulated-H_2SO_4 (IFDC-301)		2,567	2,817	2,983	2,789 ab
Mussoorie PR-AR		2,733	2,683	2,867	2,761 ab
Mussoorie PR-Conc.		2,700	2,667	2,817	2,728 ab
Mean	2,450	2,755	2,661	2,750	2,654

Source	df	F Value
Replication	2	1.64 NS
P source	9	1.50 NS
P rate	2	0.92 NS
P source x P rate	16	1.39 NS
Error	54	
Total	83	CV = 10.6%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 9. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-BIR-84 (Kharif 1984, Rice)

Source	Response Equation[a]	
TSP	$Y = 3,129 + 160.7 \ln P$	a
PAB-PAPR-50-AR (IFDC-702)	$Y = 3,129 + 200.9 \ln P$	a
PAB-PAPR-50-C (IFDC-812S)	$Y = 3,129 + 172.4 \ln P$	a
PAB-PAPR-25-AR (IFDC-816)	$Y = 3,129 + 158.8 \ln P$	a
PAP-PAPR-25-C (IFDC-813S)	$Y = 3,129 + 148.7 \ln P$	a
SAB-PAPR-50-C (IFDC-810CS)	$Y = 3,129 + 177.2 \ln P$	a
SAB-PAPR-40-AR (IFDC-605)	$Y = 3,129 + 188.9 \ln P$	a

a. Equations followed by the same letter have response coefficients which are not significantly different ($p = 0.05$).

Table 10. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-B2R-84 (Kharif 1984, Rice)

P Source	Response Equation[a]
TSP	Y = 2,573 + 89.0 ln P ab
PAB-PAPR-50-AR (IFDC-702)	Y = 2,573 + 131.0 ln P a
PAB-PAPR-15-AR (IFDC-816)	Y = 2,573 + 76.2 ln P bc
SAB-PAPR-40-AR (IFDC-605)	Y = 2,573 + 54.8 ln P bc
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 2,573 + 62.9 ln P bc
Minigranulated-H_2SO_4 (IFDC-301)	Y = 2,573 + 84.2 ln P ab
Mussoorie PR-AR	Y = 2,573 + 58.6 ln P bc
Mussoorie PR-Conc.	Y = 2,573 + 30.3 ln P c

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 11. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-K1R-84 (Kharif 1984, Rice)

P Source	Response Equation[a]
TSP	Y = 4,016 + 248.2 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 4,016 + 199.4 ln P ab
PAB-PAPR-50-C (IFDC-812)	Y = 4,016 + 268.7 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 4,016 + 177.5 ln P ab
PAB-PAPR-25-C (IFDC-813S)	Y = 4,016 + 256.3 ln P a
SAB-PAPR-50-C (IFDC-810CS)	Y = 4,016 + 249.8 ln P a
SAB-PAPR-40-AR (IFDC-605)	Y = 4,016 + 257.6 ln P a
Mussoorie PR-AR	Y = 4,016 + 150.1 ln P b
Mussoorie PR-Conc.	Y = 4,016 + 202.1 ln P ab

a. Equations followed by the same letter have response coefficients which are not significantly different ($p = 0.05$).

Table 12. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-R1R-84 (Kharif 1984, Rice)

P Source	Response Equation[a]
TSP	Y = 2,547 + 108.1 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 2,547 + 8.7 ln P b
PAB-PAPR-50-C (IFDC-812)	Y = 2,547 + 67.5 ln P ab
PAB-PAPR-25-AR (IFDC-816)	Y = 2,547 + 28.4 ln P ab
SAB-PAPR-40-AR (IFDC-605)	Y = 2,547 + 18.0 ln P a
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 2,547 + 14.8 ln P b
Minigranulated-H_2SO_4 (IFDC-301)	Y = 2,547 + 71.6 ln P ab
Mussoorie PR-AR	Y = 2,547 + 59.9 ln P ab
Mussoorie PR-Conc.	Y = 2,547 + 50.6 ln P ab

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 13. Orissa University of Agriculture and Technology, Experiment PPCL-B1P-84 (Rabi 1984/85, Green Gram), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application				Mean[a]
	0	40	80	120	
	(kg P_2O_5 ha^{-1})				
Check	795				795 b
TSP		875	904	983	921 a
PAB-PAPR-50-AR (IFDC-702)		867	912	984	921 a
PAB-PAPR-50-C (IFDC-812S)		862	958	983	934 a
PAB-PAPR-25-AR (IFDC-816)		897	940	991	943 a
PAB-PAPR-25-C (IFDC-813S)		898	962	995	952 a
SAB-PAPR-50-C (IFDC-810CS)		883	920	990	931 a
SAB-PAPR-40-AR (IFDC-605)		891	968	992	950 a
Mean	795	882	938	988	930

Source	df	F Value
Replication	2	1.29 NS
P source	7	1.42 NS
P rate	2	9.02**
P source x P rate	12	0.09 NS
Error	42	
Total	65	CV = 8.7%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 14. Orissa University of Agriculture and Technology, Experiment PPCL-B2P-84 (Rabi 1984/85, Groundnuts), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application				Mean[a]
	0	40	80	120	
	(kg P_2O_5 ha^{-1})				
Check	1,417				1,417 b
TSP		1,427	1,533	1,713	1,558 ab
PAB-PAPR-50-AR (IFDC-702)		1,410	1,517	1,747	1,558 ab
PAB-PAPR-25-AR (IFDC-816)		1,503	1,810	1,893	1,735 a
SAB-PAPR-40-AR (IFDC-605)		1,507	1,727	1,827	1,687 a
Minigranulated-H_3PO_4 (IFDC-400A)		1,443	1,630	1,737	1,603 ab
Minigranulated-H_2SO_4 (IFDC-301)		1,583	1,790	1,933	1,769 a
Mussoorie PR-AR		1,587	1,730	1,877	1,731 a
Mussoorie PR-Conc.		1,453	1,623	1,787	1,621 ab
Mean	1,417	1,489	1,670	1,814	1,598

Source	df	F Value
Replication	2	1.81 NS
P source	8	1.98 NS
P rate	2	16.43**
P source x P rate	14	0.10 NS
Error	48	
Total	74	CV = 11.9%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 15. C. B. Azad University of Agriculture and Technology, Experiment K1W-84 (Rabi 1984/85, Wheat), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	30	60	90	Mean[a]
	(kg P_2O_5 ha^{-1})				
Check	2,867				2,867 b
TSP		3,102	3,379	3,645	3,375 a
PAB-PAPR-50-AR (IFDC-702)		2,964	3,370	3,587	3,307 a
PAB-PAPR-50-C (IFDC-812S)		2,791	3,262	3,583	3,212 ab
PAB-PAPR-25-AR (IFDC-816)		3,201	3,260	3,658	3,373 a
PAB-PAPR-25-C (IFDC-813S)		2,964	3,107	3,489	3,187 ab
SAB-PAPR-50-C (IFDC-810CS)		3,009	3,505	3,994	3,503 a
SAB-PAPR-40-AR (IFDC-605)		2,814	3,173	3,551	3,179 ab
Mussoorie PR-AR		3,094	3,329	3,913	3,445 a
Mussoorie PR-Conc.		3,189	3,300	3,614	3,368 a
Mean	2,867	3,014	3,298	3,670	3,212

Source	df	F Value
Replication	2	0.72 NS
P source	9	1.59 NS
P rate	2	26.66**
P source x P rate	16	0.34 NS
Error	54	
Total	83	CV = 10.0%

a. Means followed by the same letter are not significantly different (p = 0.05) as determined by Duncan's Multiple Range Test.

Table 16. Birsa Agricultural University, Ranchi Experiment R1W-84 (Rabi 1984/85, Wheat), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	30	60	90	Mean[a]
	- - - - (kg P_2O_5 ha^{-1}) - - - -				
Check	2,338				2,338 e
TSP		2,698	2,987	3,426	3,037 bc
PAB-PAPR-50-AR (IFDC-702)		2,911	3,050	3,278	3,080 ab
PAB-PAPR-50-C (IFDC-812S)		2,996	3,137	3,371	3,168 a
PAB-PAPR-25-AR (IFDC-816)		2,910	3,101	3,032	3,014 bc
SAB-PAPR-40-AR (IFDC-605)		2,632	2,927	3,224	2,927 c
Minigranulated-H_3PO_4 (IFDC-400A)		2,489	2,508	2,687	2,562 d
Minigranulated-H_2SO_4 (IFDC-301)		2,337	2,387	2,691	2,472 d
Mussoorie PR-AR		2,340	2,411	2,743	2,498 d
Mussoorie PR-Conc.		2,435	2,473	2,551	2,486 d
Mean	2,338	2,639	2,776	3,000	2,688

Source	df	F Value
Replication	2	9.42**
P source	9	70.15**
P rate	2	83.54**
P source x P rate	16	3.48**
Error	54	
Total	83	CV = 3.72%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 17. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-B1P-84 (Rabi 1984/85, Green Gram)

P Source (Mussoorie PR)	Response Equation[a]
TSP	Y = 795 + 125.3 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 795 + 125.6 ln P a
PAB-PAPR-50-C (IFDC-812S)	Y = 795 + 139.1 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 795 + 147.3 ln P a
PAB-PAPR-25-C (IFDC-813S)	Y = 795 + 154.4 ln P a
SAB-PAPR-50-C (IFDC-810CS)	Y = 795 + 135.6 ln P a
SAB-PAPR-40-C (IFDC-605)	Y = 795 + 155.1 ln P a

a. Equations followed by the same letter have response coefficients which are not significantly different ($p = 0.05$).

Table 18. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-B2P-84 (Rabi 1984/85, Groundnut)

P Source	Response Equation[a]
TSP	Y = 1,206 + 83.7 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 1,206 + 84.1 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 1,206 + 125.8 ln P a
PAB-PAPR-40-AR (IFDC-605)	Y = 1,206 + 113.8 ln P a
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 1,206 + 94.4 ln P a
Minigranulated-H_2SO_4 (IFDC-301)	Y = 1,206 + 133.0 ln P a
Mussoorie PR-AR	Y = 1,206 + 123.6 ln P a
Mussoorie PR-Conc.	Y = 1,206 + 98.8 ln P a

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 19. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-K1W-84 (Rabi 1984/85, Wheat)

P Source	Response equation[a]
TSP	Y = 2,397 + 246.4 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 2,397 + 230.7 ln P a
PAB-PAPR-50-C (IFDC-812)	Y = 2,397 + 209.1 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 2,397 + 244.6 ln P a
PAB-PAPR-25-C (IFDC-813S)	Y = 2,397 + 199.6 ln P a
SAB-PAPR-50-C (IFDC-810CS)	Y = 2,397 + 282.5 ln P a
SAB-PAPR-40-AR (IFDC-605)	Y = 2,397 + 200.3 ln P a
Mussoorie PR-AR	Y = 2,397 + 266.3 ln P a
Mussoorie PR-Conc.	Y = 2,397 + 243.0 ln P a

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 20. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-R1W-84 (Rabi 1984/85, Wheat)

P Source	Response Equation[a]
TSP	Y = 2,134 + 229.7 ln P ab
PAB-PAPR-50-AR (IFDC-702)	Y = 2,134 + 236.3 ln P ab
PAB-PAPR-50-C (IFDC-812)	Y = 2,134 + 258.1 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 2,134 + 217.9 ln P ab
SAB-PAPR-40-AR (IFDC-605)	Y = 2,134 + 201.5 ln P b
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 2,134 + 107.0 ln P c
Minigranulated-H_2SO_4 (IFDC-301)	Y = 2,134 + 86.5 ln P c
Mussoorie PR-AR	Y = 2,134 + 93.6 ln P c
Mussoorie PR-Conc.	Y = 2,134 + 87.7 ln P c

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 21. Orissa University of Agriculture and Technology, Experiment PPCL-B3P-84 (Rabi 1984/85, Green Gram), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	40	80	120	Mean[a]
	(kg P_2O_5 ha^{-1})				
Check	813				813 c
TSP		943	968	924	945 ab
PAB-PAPR-50-AR (IFDC-702)		967	1,019	989	992 a
PAB-PAPR-25-AR (IFDC-816)		958	989	976	974 ab
SAB-PAPR-40-AR (IFDC-605)		964	994	951	970 ab
Minigranulated-H_3PO_4 (IFDC-400A)		900	931	955	929 ab
Minigranulated-H_2SO_4 (IFDC-301)		891	907	933	910 ab
Mussoorie PR-AR		837	872	957	889 bc
Mean	813	923	954	955	911

Source	df	F Value
Replication	2	2.64 NS
P source	7	3.06**
P rate	2	1.26 NS
P source x P rate	12	0.40 NS
Error	42	
Total	65	CV = 8.1%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 22. Response Function for Yield (kg ha^{-1}) of Grain Experiment PPCL-B3P-84 (Rabi 1984/85, Green Gram)

P Source	Response Equations[a]
TSP	Y = 812 + 30.3 ln P ab
PAB-PAPR-50-AR (IFDC-702)	Y = 812 + 41.5 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 812 + 37.5 ln P a
SAB-PAPR-40-AR (IFDC-605)	Y = 812 + 36.1 ln P a
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 812 + 27.3 ln P ab
Minigranulated-H_2SO_4 (IFDC-301)	Y = 812 + 23.0 ln P b
Mussoorie PR-AR	Y = 812 + 18.8 ln P b

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 23. C. S. Azad University of Agriculture and Technology, Experiment PPCL-K2W-84 (Rabi 1984/85, Wheat), Grain Yield (kg ha^{-1})

P Source	Rate of Application				Mean[a]
	0	30	60	90	
	(kg P_2O_5 ha^{-1})				
Check	3,775				3,775 b
TSP		3,790	4,442	4,591	4,274 a
PAB-PAPR-50-AR (IFDC-702)		3,813	3,896	4,068	3,926 ab
PAB-PAPR-50-C (IFDC-812S)		3,848	4,382	4,625	4,285 a
SAB-PAPR-50-C (IFDC-810CS)		3,809	4,173	4,472	4,151 ab
SAB-PAPR-40-AR (IFDC-605)		3,811	4,292	4,549	4,217 ab
Mean	3,775	3,814	4,237	4,461	4,072

Source	df	F Value
Replication	2	1.40 NS
P source	5	1.72 NS
P rate	2	11.44 **
P source x P rate	8	0.36 NS
Error	30	
Total	47	CV = 9.1%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 24. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-K2W-84 (Rabi 1984/85, Wheat)

P Source	Response Equations[a]
TSP	Y = 3,464 + 208.5 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 3,464 + 116.3 ln P a
PAB-PAPR-50-C (IFDC-812)	Y = 3,464 + 210.7 ln P a
SAB-PAPR-50-C (IFDC-810CS)	Y = 3,464 + 176.4 ln P a
SAB-PAPR-40-AR (IFDC-605)	Y = 3,464 + 193.6 ln P a

a. Equations followed by the same letter have response coefficients which are not significantly different ($p = 0.05$).

Table 25. Orissa University of Agriculture and Technology, Experiment PPCL-B3R-85 (Kharif 1985, Rice), Grain Yield (kg ha^{-1})

P Source	Rate of Application 0	40	80	120	Mean[a]
	- - - - - - -(kg P_2O_5 ha^{-1}) - - - - - -				
Check	3,252				3,252 b
TSP		3,276	3,442	3,656	3,458 ab
PAB-PAPR-50-AR (IFDC-702)		3,181	3,561	3,846	3,530 ab
PAB-PAPR-25-AR (IFDC-816)		3,478	3,989	3,929	3,799 a
SAB-PAPR-40-AR (IFDC-605)		3,443	3,585	3,727	3,585 ab
Minigranulated-H_3PO_4 (IFDC-400A)		3,312	3,704	3,751	3,589 ab
Minigranulated-H_2SO_4 (IFDC-301)		3,466	3,633	3,810	3,636 ab
Mussoorie PR-AR		3,324	3,585	3,666	3,525 ab
Mean	3,252	3,354	3,643	3,769	3,574 ab

Source	df	F Value
Replication	2	1.34 NS
P source	7	1.21 NS
P rate	2	8.52 **
P source x P rate	12	0.21 NS
Error	42	
Total	65	CV = 9.5%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 26. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-B3R-85 (Kharif 1985, Rice)

P Source	Response Equations[a]
TSP	Y = 3,009 + 107.0 ln P a
PAB-PAPR-50-AR (IFDC-702)	Y = 3,009 + 126.3 ln P a
PAB-PAPR-25-AR (IFDC-816)	Y = 3,009 + 186.5 ln P a
SAB-PAPR-40-AR (IFDC-605)	Y = 3,009 + 135.3 ln P a
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 3,009 + 138.0 ln P a
Minigranulated-H_2SO_4 (IFDC-301)	Y = 3,009 + 147.7 ln P a
Mussoorie PR-AR	Y = 3,009 + 122.2 ln P a

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table 27. C.S. Azad University of Agriculture and Technology, Experiment PPCL-K2R-85 (Kharif 1985, Rice), Grain Yield (kg ha^{-1})

P Source	Rate of Application 0	30	60	90	Mean[a]
	- - - - - - (kg P_2O_5 ha^{-1}) - - - - -				
Check	3,767				3,767 a
TSP		4,126	3,679	4,408	4,071 a
PAB-PAPR-50-AR (IFDC-702)		4,140	4,179	4,167	4,162 a
PAB-PAPR-50-C (IFDC-812S)		4,203	3,777	3,944	3,975 a
SAB-PAPR-50-C (IFDC-810CS)		4,241	4,737	4,132	4,370 a
SAB-PAPR-40-AR (IFDC-605)		4,137	3,907	4,003	4,016 a
Mean	3,767	4,169	4,056	4,131	4,097

Source	df	F Value
Replication	2	0.68 NS
P source	5	0.98 NS
P rate	2	0.20 NS
P source x P rate	8	0.83 NS
Error	30	
Total	47	CV = 12.3%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 28. Birsa Agricultural University, Experiment PPCL-R1R-85 (Kharif 1985, Rice), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	20	40	60	Mean[a]
	- - - - - - -(kg P_2O_5 ha^{-1})	- - - - - -			
Check	2,045				2,045 f
TSP		2,378	2,642	2,741	2,587 e
PAB-PAPR-50-AR (IFDC-702)		3,095	2,962	3,079	3,045 a
PAB-PAPR-50-C (IFDC-812S)		2,860	3,125	2,973	2,986 ab
PAB-PAPR-25-AR (IFDC-816)		2,753	3,061	2,905	2,906 abc
SAB-PAPR-40-AR (IFDC-605)		2,722	3,019	2,829	2,857 abcd
Minigranulated-H_3PO_4 (IFDC-400A)		2,697	2,887	2,711	2,765 bcde
Minigranulated-H_2SO_4 (IFDC-301)		2,695	2,824	2,828	2,783 bcde
Mussoorie PR-AR		2,433	2,755	2,702	2,630 de
Mussoorie PR-Conc.		2,548	2,678	2,798	2,675 cde
Mean	2,045	2,687	2,884	2,841	2,777

Source	df	F Value
Replication	2	0.34 NS
P source	9	8.50 **
P rate	2	6.37 **
P source x P rate	16	0.58 NS
Error	54	
Total	83	CV = 7.7%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table 29. Response Functions for Yield (kg ha^{-1}) of Grain Experiment PPCL-R1R-85 (Kharif 1985, Rice)

P Source	Response Equations[a]
TSP	Y = 2,096 + 138.7 ln P e
PAB-PAPR-50-AR (IFDC-702)	Y = 2,096 + 257.9 ln P a
PAB-PAPR-50-C (IFDC-812S)	Y = 2,096 + 244.1 ln P ab
PAB-PAPR-25-AR (IFDC-816)	Y = 2,096 + 223.1 ln P abc
SAB-PAPR-40-AR (IFDC-605)	Y = 2,096 + 209.1 ln P abcd
Minigranulated-H_3PO_4 (IFDC-400A)	Y = 2,096 + 182.7 ln P cde
Minigranulated-H_2SO_4 (IFDC-301)	Y = 2,096 + 188.8 ln P bcde
Mussoorie PR-AR	Y = 2,096 + 149.4 ln P e
Mussoorie PR-Conc.	Y = 2,096 + 160.9 ln P de

a. Equations followed by the same letter have response coefficients which are not significantly different (p = 0.05).

Table A1. G. B. Pant University of Agriculture and Technology, Experiment PPCL-P1C-84 (Kharif 1984, Corn), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	25	50	75	Mean[a]
	- - - - - - - (kg P_2O_5 ha^{-1}) - - - - -				
Check	4,087				4,087 a
TSP		4,651	4,681	4,690	4,671 a
PAB-PAPR-50-AR (IFDC-702)		4,510	4,141	4,628	4,427 a
PAB-PAPR-50-C (IFDC-812S)		4,243	4,386	3,854	4,161 a
PAB-PAPR-25-AR (IFDC-816)		4,607	4,455	4,327	4,463 a
PAB-PAPR-25-C (IFDC-813S)		4,771	4,599	4,286	4,552 a
SAB-PAPR-50-C (IFDC-810CS)		4,050	4,034	4,488	4,191 a
SAB-PAPR-40-AR (IFDC-605)		4,715	4,897	3,967	4,526 a
Mean	4,087	4,507	4,456	4,320	4,412

Source	df	F Value
Replication	2	0.12 NS
P source	7	1.36 NS
P rate	2	0.83 NS
P source x P rate	12	0.98 NS
Error	42	
Total	65	CV = 11.1%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table A2. G. B. Pant University of Agriculture and Technology, Experiment PPCL-P1W-84 (Rabi 1984/85, Wheat), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application				Mean[a]
	0	25	50	75	
	(kg P_2O_5 ha^{-1})				
Check	4,222				4,222 a
TSP		4,555	4,028	4,160	4,248 a
PAB-PAPR-50-AR (IFDC-702)		4,611	4,222	4,611	4,481 a
PAB-PAPR-50-C (IFDC-812S)		4,637	4,417	4,331	4,461 a
PAB-PAPR-25-AR (IFDC-816)		4,221	4,083	4,611	4,305 a
PAB-PAPR-25-C (IFDC-813S)		4,527	5,111	4,277	4,639 a
SAB-PAPR-50-C (IFDC-810CS)		4,694	4,027	4,139	4,287 a
SAB-PAPR-40-AR (IFDC-605)		4,513	4,861	4,720	4,698 a
Mean	4,222	4,537	4,393	4,407	4,435

Source	df	F Value
Replication	2	11.36 **
P source	7	1.20 NS
P rate	2	0.61 NS
P source x P rate	12	1.20 NS
Error	42	
Total	65	CV = 10.5%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table A3. G. B. Pant University of Agriculture and Technology, Experiment PPCL-P2W-84 (Rabi 1984/85, Wheat), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application 0	25	50	75	Mean[a]
	- - - - - - - (kg P_2O_5 ha^{-1}) - - - - -				
Check	4,239				4,239 a
TSP		4,526	4,165	4,234	4,308 a
PAB-PAPR-50-AR (IFDC-702)		4,470	4,234	4,648	4,450 a
PAB-PAPR-25-C (IFDC-813S)		4,315	4,630	4,151	4,365 a
SAB-PAPR-50-C (IFDC-810CS)		4,192	4,428	4,539	4,387 a
SAB-PAPR-40-AR (IFDC-605)		4,111	4,303	4,345	4,253 a
Mean	4,239	4,323	4,352	4,383	4,346

Source	df	F Value
Replication	2	1.83 NS
P source	5	0.42 NS
P rate	2	0.12 NS
P source x P rate	8	1.18 NS
Error	30	
Total	47	CV = 7.8%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.

Table A4. G. B. Pant University of Agriculture and Technology, Experiment PPCL-P2C-85 (Kharif 1985, Corn), Grain Yield (kg ha^{-1})

P Source (Mussoorie PR)	Rate of Application				Mean[a]
	0	25	50	75	
	(kg P_2O_5 ha^{-1})				
Check	2,305				2,305 ab
TSP		2,098	1,835	1,956	1,963 b
PAB-PAPR-50-AR (IFDC-702)		2,360	2,501	2,791	2,550 ab
PAB-PAPR-25-C (IFDC-813S)		3,030	3,226	2,483	2,913 a
SAB-PAPR-50-C (IFDC-810CS)		2,601	2,345	2,266	2,404 ab
SAB-PAPR-40-AR (IFDC-605)		2,407	2,398	3,002	2,602 ab
Mean	2,305	2,499	2,461	2,499	2,475

Source	df	F Value
Replication	2	2.04 NS
P source	5	2.71 *
P rate	2	0.02 NS
P source x P rate	8	0.83 NS
Error	30	
Total	47	CV = 23.08%

a. Means followed by the same letter are not significantly different ($p = 0.05$) as determined by Duncan's Multiple Range Test.