

Phosphorus in Indian Agriculture - Past, Present and Future

Dr. H. L. S. TANDON
Director, Fertiliser Development and Consultation Organisation,
C-110, Greater Kailash I, New Delhi-110 048.

Reprinted from :


Fertiliser Industry
ANNUAL REVIEW

1986 Edition — Vol. IX, pp. 37-44

Published by :

SPECIALISED PUBLICATIONS
Chaves House, 1st Floor, 1 Khotachi Wadi,
V. P. Road, Bombay-400 004.

Phosphorus in Indian Agriculture - Past, Present and Future

Dr. H. L. S. TANDON,

Director, Fertiliser Development and Consultation Organisation, C 110, Greater Kailash I, New Delhi-110 048

ABSTRACT

This paper provides some highlights of 30 years of Phosphorus research and usage in India with likely future trends upto the 1990-2000 decade. It is based on a more comprehensive report on "Phosphorus Research and Agricultural Production in India" published by The Fertiliser Development and Consultation Organisation.

INTRODUCTION

FERTILISERS have contributed handsomely towards making India self-sufficient in foodgrain production. The production of 60 million tonnes or 40% of the total current food output can be attributed to fertilisers (Randhawa and Tandon, 1982). Thus the food available for two out of every five persons can be described as "fertiliser-born".

The consumption of fertiliser nutrients has increased from about 60 thousand tonnes to 8.5 million tonnes during the last 35 years. India today ranks 4th in the usage of N, 6th in P and 8th in K. Phosphorus accounts for 23% of the total fertiliser nutrients used. The phosphorus scenario has been packed with developments on several fronts — the growth in volume of usage, product-pattern, domestic production and imports, inter-country ventures, and various facets of soil and fertiliser research aimed at developing agro-techniques for achieving optimum, balanced and efficient use of the fertiliser phosphorus.

This paper provides some highlights of 30 years of phosphorus research and usage in India with possible future trends upto the 1990-2000 decade. It is based on a more detailed status report on "Phosphorus Research and Agricultural Production in India" by FDCO (Tandon, 1986).

DEVELOPMENTS IN PHOSPHORUS USAGE

The Product Pattern

The P-fertilisers used in India consist of superphosphates, ammonium phosphates, urea-ammonium phosphates, ammonium nitrate phos-

phates (nitrophosphates or ANPs), NPK complexes and to a smaller extent powdered rock phosphates (Table 1). Chronology of production of different P-carriers shows that no major new product has been added since the late 1960s. During the 1970s, the water solubility of nitrophosphate 20-20-0 was upgraded from 30% to 50-60%.

Single Superphosphate which was the major P-fertiliser in the earlier years, today accounts for about 16% of the P-usage, the remaining 84% being through various NP/NPK materials and 1% through powdered rock phosphate. Diammonium phosphate is the single most widely used P-fertiliser as half of all P distributed in India is as DAP. In the northern states (wheat belt), DAP delivers 70% of the total P used. The share of domestic production and imports in the P distribution pattern is in the ratio of 70:30. Phosphorus is now imported as DAP (alongwith phosphate rock and phosphoric acid), though during the 1970s, a variety of NP/NPK complexes were also imported.

Table 1 — Chronology of Production of Phosphatic Fertilisers in India

Year of First Manufacture	Fertiliser	Units Operating in 1986
1906	Single superphosphate	60
1960	Ammonium phosphate	2
1965	Nitrophosphates (30% WS)	1
1967	Diammonium phosphate	5
1968	Triple superphosphate	3
	Urea Ammonium phosphate	4
	NPK Complexes (High WS)	4
1973	Pelophos	0
1983*	Liquid NP fertiliser	
1987	Partially Acidulated Phosphate Rock	
1987	Polyphosphates (pilot scale)	
1989	Nitrophosphate (High WS)	

* Experimental scale (S. K. Saha, PPCL, personal communication Data sources upto 1973 from FAI Fertiliser Statistics.

Most of the P-fertilisers currently on the scene are expected to be there in future as well. The proportion of SSP and DAP could further increase. Among other changes foreseen are the availability of high-water-soluble nitrophosphates, some partially acidulated phosphate rock products (PAPR), and perhaps some polyphosphates and liquid nitrophosphates (4-4-0). Single superphosphate which has staged a major comeback in recent years, is expected to have an installed capacity of 5 million tonnes by 1990 as compared to 3 mt at present.

The Tonnage

Phosphorus consumption was 7 thousand tonnes P_2O_5 in 1951. Today, it is nearing 2 million tonnes (Table 2). If one takes 1950 as the benchmark, then it took 28 years to reach the one million tonne mark (1978-79), 8-9 years to reach the two million tonne mark, and available projections indicate that the third million may take only 4 years or so. Such is the pace of development, necessitated by the urgency to feed an ever-increasing population. The population of India was 360 million in 1951 as against 750 million at present. It is a tribute to agricultural development in India that while the population increased by 108%, foodgrain production increased by 188% (from 52 to 151 mt.) during the same period.

Future projections indicate a likely consumption level of 3.2 million tonnes P_2O_5 by 1990 around 6 million tonnes by 2000 AD. Whether and when India will become self-sufficient in the production of P-fertilisers is a big ?. This is even if the fertiliser granules assembled locally from imported phosphate rock and phosphoric are considered as "domestically-produced P".

Table 2 — Production and Consumption of Phosphorus in India — Past, Present and Future

Year	Million Tonnes P_2O_5	
	Production	Consumption
1970	0.22	0.42
1975	0.33	0.47
1980	0.76	1.15
1985	1.32	1.89
1990	2.19	3.23*
2000	?	6**

Data source : FAI Fertiliser statistics and publications *demand projection; **As 25% of the 25 million tonnes $N+P_2O_5+K_2O$ consumption currently being mentioned at present.

Table 3 — Trends in the Consumption of Phosphorus in Some Selected States of India — Past, Present and Future

Year	Kg P_2O_5 /ha gross cropped area				
	Punjab	Tamil Nadu	Madhya Pradesh	Orissa	All-India
1965	0.4	2.0	0.4	0.2	0.8
1970	4.1	5.7	0.8	0.6	2.6
1975	7.5	6.8	1.5	1.3	2.9
1980	27.9	12.8	2.3	1.7	6.7
1985	38.5	20.0	5.7	3.1	10.6
1990	?	?	?	?	18.0*
2000	?	?	?	?	30.0**

Compiled from FAI Fertiliser Statistics.

* Based on consumption of 3.2 million tonnes and gross cropped area of 180 million ha by 1990.

** Based on consumption of 6 million tonnes and gross cropped area of 200 million ha by 2000 AD.

Usage per Unit Area

Although India is the 6th largest user of fertiliser P, average consumption has reached 11 kg P_2O_5 /ha (Table 3). For a country with 177 million hectares of gross cropped area, it takes a consumption jump of 177,000 tonnes P_2O_5 to register an increase of 1 Kg/ha. Per hectare P consumption varies widely among states (from negligible to 40 Kg/ha) and even within districts in a state. In 1985, there were 62% districts of India which had a mean P_2O_5 consumption of 10 Kg/ha or less (Table 4).

In the Punjab state, where mean usage of P/ha is the highest at 40 Kg P_2O_5 /ha, the growth

Table 4 — Classification of 370 Districts of India According to Mean Level of P Application Attained by 1985

Mean P_2O_5 Consumption Kg P_2O_5 /ha	Number of Districts	Percent of Total Districts
10 or less	226	61
11 - 20	100	27
21 - 40	33	9
41 - 60	11	3

Data source : FAI Fertiliser Statistics for 1985. Also Tandon (1986)

in P consumption has gone hand in hand with the spread of high-yielding cereal varieties from mid 1960s onwards. It is not widely recognised that even around 1965, the average P consumption in Punjab was no different than P usage in Madhya Pradesh and was much less than in Tamil Nadu state, for example. To the author, the growth of P consumption in Punjab is the result of an unanimity between the researcher-administrator-extension worker and the farmer that the HYVs will not give of their best if cropped with N alone. Not to be forgotten is the key role in making available adequate supplies of P-fertiliser to the farmers.

As already shown in Table 4, mean usage of P_2O_5 /ha has developed to 11-20 Kg in 27% districts and 41-60 Kg in only 3% districts. About 60% districts are below the average national P consumption. Projections of P use indicate attainment of 18 Kg P_2O_5 /ha by 1990 and 30 Kg by 2000 AD. Although these levels no doubt represent sizable improvement over present levels, barring few areas, on the whole Indian soils may continue to be depleted of P due to a negative balance on a net basis. Soil fertility buildup seems to be a distant goal.

Price of Fertiliser P

Selected data on the maximum all-India retail prices of fertiliser P for the 1972-1986 period are shown in Table 5. At present, the per Kg price of P_2O_5 is Rs. 5.94 (SSP), Rs. 5.83 (DAP); Rs. 6.72-8.25 (NP/NPK complexes) and Rs. 3/Kg (powdered rock phosphate). At the farmer's level these prices get modified because of varying levels of local taxes and subsidies provided in different states for special schemes and certain groups of farmers or the ease of accessibility of an area. The economics of fertiliser use calculated using all-India prices provide an overall picture but do not necessarily reflect the exact situation in different regions. A few examples

of state-level subsidies on phosphatic fertilisers are given below to illustrate the point and the need for a more comprehensive economic analyses of fertiliser responses :

Haryana : 10% subsidy on P for Chickpeas
 Manipur : 25% subsidy on DAP
 A&N Islands : 25% subsidy on cost + 100% on transport
 Andhra Pradesh : 25% subsidy to small farmers, 33% to marginal farmers
 Himachal Pradesh : 40% subsidy to all farmers
 Karnataka : 75% subsidy under tribal sub-plan schemes

DEVELOPMENTS IN PHOSPHORUS RESEARCH

Research on phosphorus has been a part of the overall soil and fertiliser research but no project or institute is devoted exclusively to this nutrient. Within the overall growth in research, P has been given its due importance at least extensively if not intensively. Researches accomplished have been periodically reviewed (FAI, Fertiliser News — Special Agronomy Numbers; Indian Society of Agronomy; Indian Society of Soil Science 1979, 1982; Goswami and Kamath 1984, Tandon 1986; IMPHOS-FAI Seminar of January 1986 and others).

Landmarks in P Research

The major initiatives in phosphorus research in India are listed in Table 6. These depict the evolution of thoughts and priorities in P research. The beginning was rather modest, in line with the early stages of development (field trials, search for workable soil tests etc). A definite impetus to research was provided by the establishment of agricultural universities (now 24), reorganisation of the ICAR, initiation of multi-locational coordinated research projects, arrival of high yielding crop varieties and the introduction of complex fertilisers.

Table 5 — Retail Price of Phosphorus and Procurement Prices of Rice and Wheat in India

Date	Rs/Kg P_2O_5			Procurement price Rs/Kg	
	SSP	DAP	RP*	Paddy	Wheat
1972	2.89-5.53	1.86	—	0.53	0.76
1975	5.33-5.93	4.83	—	0.74	1.06
1981	4.88-6.11	5.83	—	1.05	1.30
1983	5.31	5.46	—	1.22	1.51
1986(mid)	5.94	5.83	3.00	1.46	1.60
1990	?	?	?	?	?

* Powdered phosphate rock for direct application

Table 6 — Some Landmarks in Phosphorus Research in India

Year/ Period	Landmark
1953	Model Agronomy Experiment Scheme
1955	Chain of 24 Soil Testing Laboratories
1960s	Reorganisation of ICAR, Establishment of Agricultural universities in the states
1960s(mid)	Accentuation of P-deficiencies with introduction of high-yielding varieties where cropped without P
1960s	Emergence of new fertilisers such as nitrophosphates, other complex fertilisers (NP/NPK)
1967	Coordinated Soil Test Crop Response Correlation Project
1970	All India Coordinated Research Project for Dryland Agriculture (now Central Institute for Dryland Agriculture)
1971	Longterm Fertiliser Experiment Project (using HYVs)
1970s	Emphasis on P-management in cropping systems after the "oil crisis"
1970s	Acceleration of interest in using powdered rock-P for direct application
1980s (emerging and expected)	Partially acidulated phosphate rocks (fertiliser-grade), polyphosphates, Phosphal, liquid fertilisers, models for residual effects, prediction of rates of accumulation and decline of P in intensive cropping systems, intensification of research on mycorrhiza, P-solubilising micro-organisms, application of computers

Most initiated projects are continuing. Number of soil testing labs 425.

During the 1960s researches were initiated on the agronomic evaluation of P-fertilisers varying in water-solubility parallel to the production of nitrophosphates having 30% water-soluble P component. In later years, this subject became less important and the focus shifted to the study of indigenous phosphate rocks for direct application. The coordinated projects on agronomy, dryland agriculture, soil-test crop response correlations, and the longterm fertiliser experiments represent the quartet of modern fertiliser research in India which regularly generated, and continue to generate valuable

data on P management and its various aspects. The "oil crisis" of the early 1970s can be held responsible for hastening the emphasis on studying P management on cropping system basis rather than for individual crops in isolation.

Phosphorus-Fertility of Soils

Phosphorus deficiency is widespread in Indian soils (Table 7). How acute this is in how much acreage, we do not know. With the advent of HYVs, increase in cropping intensity and yield levels, it appears that the medium fertility category developed for the tall varieties is also deficient in P and highly responsive to P as shown by numerous field data summarised elsewhere (Tandon, 1986).

The district-level P fertility maps as assembled at present may be useful in focussing attention on the problem but cannot be used for developing P allocation plans or P recommendations. This is because a given soil test value does not represent the same size pool of available P in different soils, for different crops or even in different seasons at the same site. Upto now, no clear relation is visible between soil fertility and P consumption. Perhaps such associations will emerge when P-usage has developed to moderate-high levels. It does appear that in most cases, N follows irrigation and P follows N.

Soils in 98% districts require P application for high yields whether agriculture is irrigated or rainfed (Kanwar 1986, Venkateswarlu 1986). Soil fertility maps at the village/block/taluka level are increasingly being made to move a step farther from district level maps. Soil fertility evaluation in future must coordinate closely with soil survey research and a systematic plan for cataloging and monitoring soil fertility on well-characterised benchmark sites would appear necessary. Perhaps one day, farmers would have a "passbook" for each field in which the soil properties, the cropping pattern, the inputs applied, the yields harvested and the nutrients removed will all be catalogued. If even the smallest transaction can be entered into a bank passbook, why not in a soil accountbook?

There is no doubt that soil testing is a very useful facility for providing sound fertiliser recommendations (Velayutham, 1985). While we know what soil testing can do, we have little idea of the role it has played in directing the application of 2 million tonnes of P_2O_5 used annually. It does appear that field verification, organisation and management are the major issues in energising soil testing services rather than the chemistry as such. Future

Table 7 — Phosphorus Fertility of Indian Soils

Year	District Studied	% Districts with P-fertility			Reference
		low	medium	high	
1969	226	47	49	3	Ramamoorthy and Bajaj (1969)
1979	363	46	52	2	Ghosh and Hasan (1979)
1986	370	45	50	5	Tandon (1986)

efforts may be directed in transforming the 425 soil testing laboratories (most of them) into time-bound, professionally managed, service facilities rather than charitable dispensaries. There are a number of excellent soil testing laboratories in the country which could serve as models.

Crop Requirement of Phosphorus

Cereal crops absorb about 8-10 Kg P₂O₅ for every tonne of grain produced. Nutrient uptake data have been generated for a number of crops. A number of these are listed in the FAI Fertiliser Statistics and other references. A few estimates for selected crops are given in Table 8. Much of the P present in harvested crops is still coming from the soil reserves plus residues of previous additions. Some recent calculations show that out of the total phosphorus removed by crops in India, the soil contributes 78%, fertilisers 14% and organic manures 8%, indicating continued heavy dependence on soil reserves.

For future research, it may be worthwhile to (i) differentiate between gross P uptake and actual P requirement to exclude any luxury consumption (ii) develop crop varieties with high P use efficiency at various points, that is for absorption of P from the soil and for utilising absorbed P for yield production.

Phosphorus Removals in Agriculture

It is estimated that agricultural crops are removing about 2.6 million tonnes of P₂O₅

Table 8 — Mean P Requirement of Crops per Tonne Yield Production

Crop	Kg P ₂ O ₅ absorbed per tonne yield production
Cereals	10
Pulses	14
Oilseeds	24
Tubers	2
Jute	15
Coffee	18
Tea	38

annually (Table 9). Foodgrains account for 65 percent of this. Whereas for most foodcrops, P uptake can be roughly equated with P removal, this cannot be so for plantations or sugarcane fields where the contribution of leaf fall and residue recycling cannot be ignored. For tree crops/perennials, the P mobilised in the trunk, branches etc is P removal for all practical purposes. On a gross basis, the P balancesheet of Indian agriculture comes out as positive (contribution of fertilisers + manures — crop uptake) but on a net basis, the balancesheet is negative. In an interesting field study, Prasad et al (1985) have shown the dynamic inter-play between P additions, P removals, Yield levels and soil-P balances in intensive cropping sequences. These and other reports (Nambiar and Ghosh 1984) show that P balances are not always positive when the currently recommended P rates are used.

Future estimates of P removals are essentially tied up with the foodgrain production figures. If the food grain production by 2000 is 225 m.t. (50% above present level), then P removals may reach 3.9 million tonnes P₂O₅ assuming no drastic changes in cropping pattern. If the foodgrain target is raised to 240 m.t. then expected P removals could be higher at 4.2 million tonnes.

Table 9 — Mean Annual Removals of Phosphorus in Indian Agriculture—Past, Present and Future

Year	Removal, Million Tonnes P ₂ O ₅		
	Foodgrains	Other Crops	Total
1965	0.98	0.52	1.50
1974	1.18	0.51	1.69
1985	1.70	0.90	2.60
2000	2.55	1.35	3.90

Most data based on Reports of the National Commission on Agriculture (1976). Data for 2000 based on 50% increase over 1985 levels being proportionate to the increase expected in agricultural production during the 1985-2000 period.

A large number of gaps in our information need to be filled if sound P balancesheets are to be constructed. Studies on inter-regional migration of P through crops transported would also be interesting. For example, if a grain-surplus state A "exports" one million tonnes wheat (Removal of 10,000 t P_2O_5), then should its farmers receive on priority 50,000 t fertiliser P_2O_5 (50,000 at 20% efficiency will put 10,000 in the crop) to sustain productivity, and to maintain if not build up the fertility of their soils?

Efficient Use of Phosphorus

A fair amount of P research in India has been directed at the twin goals of nutrient ba-

lance and nutrient efficiency, and rightly so. The growth, diversification and maturity in P research is well reflected in the trends of P efficiency research (Table 10). Few approaches once taken up have been given up so that the list rather swells with time. While this could be because the solutions to many problems require extended research, it could also be that research priorities are not periodically evaluated and restructured.

During the 1950s, P efficiency research was not of major concern. Usage of fertiliser P increased from 7000 to 53000 tonnes P_2O_5 in this decade. During the 1960s, P efficiency research

Table 10 — Evolution of Priorities for P efficiency Research in India

	1960s	1970s	1980s (actual and suggested)
Soil Tests	Soil Tests	Soil tests for targetted yields	Soil tests for targetted yields
Methods of application	Methods of application P responsive varieties (HYV) Evaluation of P sources having range of water solubilities District-level P fertility maps	Soil tests for targetted yields Rooting patterns (32P) and methods of P application P management in cropping systems Dipping rice roots and seed tubers in P slurry and solutions Evaluation of nitrophos, rock-P, polyphosphates Research on mycorrhiza, P solubilising micro-organisms Interactions of P Revised District-level P fertility map	Times and methods of application P management in cropping systems & accounting for residual effects Evaluation of PAPRs and polyphosphates on field scale Integration of rock P with organic materials, pyrites, microbial inputs Expansion in mycorrhiza research to tap residual P in soil Interactions involving P and their agro-economic quantification Development of village/taluka/block level P fertility maps, use of computers in making and monitoring P recommendations for efficient use. Exercises in matching P application/distribution plans with soil P status and crop production potentials.

started receiving attention. The higher rates of P recommended for the HYVs demanded this. While research on soil testing and methods of P application continued, field experiments brought out the HYVs themselves as a vehicle for making efficient use of applied nutrients. Research on the efficiency of P carriers varying in water-soluble P became important as India started producing nitrophosphates at Trombay. Research data generated by the soil testing laboratories was processed into a district-level map of P fertility by Ramamoorthy and Bajaj (1969). The usage of P during this decade increased from 53000 to 416,000 tonnes P_2O_5 .

During the 1970s, the earlier programmes of P research were carried forward and facilities for isotopic research were strengthened. A significant development was the emergence of emphasis on managing P on cropping system basis and integrated use of organic + inorganic sources. Evaluation of various P fertilisers continued but the emphasis shifted from nitrophosphates (Sekhon, 1979) to powdered rock phosphate for direct application (Jaggi 1986) and materials such as Phosphal. Data were generated on the efficacy of dipping rice roots and potato tubers in P solutions/slurries to economise on P use. Work was also expanded on the integration of rock-phosphate with organic materials (Khanna et al 1983), mycorrhiza (Krishna 1985) and on P solubilising micro-organisms (Gaur 1983). The importance of interactions involving P started getting noticed. Soil testing research was setup on the promise of furnishing tailor-made recommendations for pre-set yield targets. A revised and enlarged P fertility map was prepared (Ghosh and Hasan 1979). At the state level, the emphasis shifted to village/block/taluka level maps. The number of soil testing laboratories approached 400. Phosphate consumption during the 1970s increased from 541,000 to 1,151,000 tonnes P_2O_5 .

During the 1980s, P efficiency research has gained notable strength in the areas of P management in cropping systems; technologies for the integration of rock-P with organic materials, pyrites and microbiological inputs for higher efficiency; P dynamics and balances in intensive crop rotations (2-4 crops/year); and study of interactions. Research efforts on mycorrhiza and P solubilising micro-organisms are also being stepped up but there is little evidence of an interaction between microbiologists and soil scientists/agronomists. With the coming up of a trial plant of PAPR, interest in evaluating fertiliser-

grade PAPRs could re-open the question of optimum water solubility of P. Research with polyphosphates and liquid NP fertilisers which at present is on a small scale, could gain momentum.

Future strategies on P efficiency research are not expected to be drastically different than the present approaches. However, first of all, the loose ends in the voluminous data available will have to be tied up through answer-seeking in-depth experiments. It may be crucial to discard single-season P response trials and rather invest resources in a lesser number of well-planned medium-longterm experiments on adequately characterised sites. Site characterisation and advance planning become even more important in such experiments because once laid out these cannot be shifted. Nutrient monitoring surveys on soils and standing crops provide useful information as shown by the Punjab experience and such studies could be expanded. Quantification of residual effects and accounting for them in calculating P response yardsticks and economics should receive priority. For fertility monitoring soils may be samples beyond the 0-15 cm depth. The widespread practice of equating the quick soil test value with the total pool of available P ought to be deliberated and its merit/demerit brought out. Rates of P buildup and depletions under different management levels and P recommendations for soils builtup to a certain level of available P will be important issues taking into account sustained production of high yields, maintenance of soil fertility and the economics of crop production. For a more efficient utilisation of the residual P in soils, help may be sought from efficient genotypes and the plant-mycorrhiza association.

Computers can play a role in soil fertility monitoring and fertiliser management. They would be particularly useful for continuously updating soil fertility maps, for cataloging, correlating and monitoring the nutrient status of standing crops, correlating soil deficiencies with fertiliser consumption pattern and for giving out fertiliser recommendations for a range of investment capacities in order to cater to farmers of different income groups. If soil testing services are organised on time-bound professionally managed lines, it will have better scope for contributing towards more efficient use of P on Indian farms.

In conclusion, blueprints must now be developed to make the most balanced and efficient

use of the nearly 6 million tonnes of P_2O_5 which the country aims to use by 2000 AD. The size and capability of the research community, the vast extension network and the dynamism of the fertiliser industry provide the hope that it can be done. The only question is how thoroughly and how soon?

REFERENCES

1. Fertiliser Association of India, Fertiliser Statistics annual volume and other publications, special issues of Fertiliser News.
2. Gaur, A.C., 1983. Bio. fertilisers and Crop Productivity, *Advances in Soil Science*, New Delhi, 127-178.
3. Ghosh, A.B. and Hasan, R., 1979; Phosphorus Fertility of Indian Soils, Bulletin 12, Indian Society of Soil Science, 1-8.
4. Goswami, N.N. and Kamath, M.B.; 1984; Phosphate Management in Soil Crop Systems in India, Proc. FAI Annual Seminar, II-2 (ii)/1-23.
5. Indian Society of Agronomy, 1980, Quarter Century of Agronomic Research in India (1955-1980).
6. Indian Society of Soil Science, 1979, Phosphorus in Soils, Crops and Fertilisers, Bulletin No. 12. and 1982, Review of Soil Research in India, Part I.
7. Jaggi, T.N., 1986, Direct Application of Low-grade Phosphate Rock in Acidic Soils, IMPHOS-FAI Seminar papers, New Delhi.
8. Kanwar, J.S., 1986; Crop Production Techniques and Fertiliser Management with Special Reference to Phosphate Fertiliser in Rainfed Areas IMPHOS-FAI Seminar papers, New Delhi.
9. Khanna, S.S. et al, 1983, Efficiency of Incubated Phosphatic Fertilisers Varying in Water Solubility with Organic Matter to Wheat, Proc. 3rd International Congress on Phosphorus Compounds, Brusells, 567-579.
10. Krishna, K.R., 1985, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Personal Communication.
11. Nambiar, K.K.M. and Ghosh, A.B., 1984; Highlights of Research on Longterm Fertiliser Experiment, 1971-1982; Longterm Fertiliser Experiments Project, New Delhi, Tech. Bulletin No. 1, pp. 100.
12. National Commission on Agriculture, Government of India, 1976, Volume 10 (INPUTS) of the report.
13. Prasad, R. et al, 1985, Phosphate Fertilisation in Intensive Annual Cropping with Wheat-greengram (or cowpea)-pearl millet, *Fertiliser Research*, 6, 219-224.
14. Ramamoorthy, B. and Bajaj, J.C. 1969; available Nitrogen, Phosphorus and Potassium Status of Indian Soils, *Fertiliser News*, 14(8), 25-36.
15. Randhawa, N.S. and Tandon, H.L.S., 1982; *Advances in Soil Fertility and Fertiliser Use Research in India*, *Fertiliser News*, 27(2), 11-26.
16. Sekhon, G.S., 1979, Comparative Efficiency of Materials Differing in Water Solubility, Bulletin No. 12, Indian Society of Soil Science, 193-201.
17. Singh, Bhajan and Brar, S. P.S., 1986 Long-term Effect of NPK and Zn Fertilisation in Maize-wheat Rotation on Crop Yield and Soil Characteristics (1970-1984), Punjab Agricultural University Ludhiana (mimeographed) bulletin).
18. Tandon, H.L.S., 1986 Phosphorus Research and Agricultural Production in India, Fertiliser Development and Consultation Organisation, New Delhi, pp. 200 (in press).
19. Velayutham, M. et al, 1985, All India Coordinated Research Project on Soil Test Crop Response Correlations and its Impact on Agricultural Production, *Fertiliser News*, 30(4), 81-96.
20. Venkateswarlu, J., 1986, Rainfed Farming and Phosphate Fertiliser Management, IMPHOS-FAI Seminar papers, New Delhi.