PN-ABK-432
ISN 76761

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Reprinted from *Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania* (proceedings of a symposium, 6-10 March 1989) International Rice Research Institute, 1990

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

1776 Massachusetts Avenue, N.W.,
Washington, D.C. 20036 1998 U.S.A.

Reprint No. 216

Phosphorus for sustainable agricultural growth in Asia: an assessment of alternative sources and management

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Sustainable agricultural growth in most of the developing countries of Asia implies sustainability of growth in yields through intensive cultivation of land. Two necessary conditions for such growth are improvements in crop varieties and high soil fertility. This paper highlights evidence on the P constraint. It also reviews the experience of growth in fertilizer use to overcome soil fertility constraints. The three most important problem areas are identified: 1) low use of organic manure outside East Asia, 2) persistent geographical concentration of fertilizer use within countries, and 3) much less use of P than of N fertilizers. To sustain yield-based agricultural growth in the developing countries of Asia, effective mechanisms are urgently required to deal with soil fertility constraints in a dynamic context. A reorientation in policies is necessary to develop such mechanisms

Sustainable agricultural growth in most of the developing countries of Asia implies sustainability of growth in yields through intensive land cultivation. The experience of the last 25 yr reveals that this requires developing crop varieties with high yield potential as well as effectively tackling soil fertility constraints.

An overview of the experience leads to three broad conclusions: 1) Well-coordinated efforts in both the above directions are critical for developing sustainable intensive cultivation of land. 2) Although fertilizers are becoming more important in supplying plant nutrients, there are major deficiencies in the policies and efforts designed to tackle soil fertility constraints through fertilizers. 3) It is urgent to remove those deficiencies because intensive cultivation is increasingly constrained, both in technical and economic terms, by the fertility status of soils.

Dynamics of soil fertility constraints in Asia

It has been known for a long time that Asian soils are remarkably deficient in N, but the severity of other nutrient deficiencies has not been as commonly recognized. According to Ignatieff and Page (1958), the manifestation of other nutrient deficiencies was only a matter of time. During the last two decades, this has indeed proved correct.

In the case of P, the deficiency occurred despite substantial growth in the use of P fertilizers.

In Asia it is especially necessary to examine soil fertility constraints in a dynamic context. The unprecedented yield-based growth in production has stepped up nutrient removal from limited arable land, which in most countries has not been matched by commensurate and balanced growth in the supply of nutrients through organic sources and fertilizers. In India, for instance, N, P, and K removed by crops increased by 70% between 1961 and 1984, reaching the equivalent of 17 million t of aggregate $N + P_2O_5 + K_2O$ by 1984. Although estimates of *net* supply of nutrients through organic matter (OM) and chemical fertilizers vary widely, they fall short of nutrients removed through crop production. Thus, together with loss of nutrients due to soil erosion, grazing, etc., soil fertility has decreased.

That the fertility constraints have not been overcome is suggested by the smaller than expected effects on yields of increasing fertilizer use and even a decline in the efficiency of fertilizer use before the full genetic potential of available varieties is fully realized (Ahmed 1985; Pakistan 1988; Randhawa and Meelu 1975; Sarma and Gandhi, unpubl. data; Stone 1986). A wide variety of factors are responsible for this, but the importance of fertility constraints cannot be denied. Regional variations in levels and growth of yields at comparable levels of irrigation, diffusion of modern varieties (MVs), and N use, as well as farm-level evidence in research on yield-gap analysis, point in this direction. On land planted to MVs but not receiving fertilizer, fertility constraints seem to have become more severe, as indicated by declines in average wheat yields in about 7,500 trials conducted in farmers' fields in India between 1967 and 1982 (Tandon 1987).

Soil fertility problems are not confined to P, as the evidence from a growing number of locations indicates for deficiencies of S and micronutrients. But P deserves special attention for four reasons: first, next to that of N, deficiency in available P is most widespread in many Asian countries. For instance, the commonly used soil test methods show that 46% of the districts in India were classified as "low" in available P, 50% as "medium," and only 4% as "high" (Tandon 1987). Furthermore, the proportion of districts with severe P deficiency has increased over time. In China, too, a similar pattern is indicated. During the 1930s, about 30% of China's farmland was considered P deficient. Estimates for the 1950s varied between 40 and 55% (Stone 1986). Recently, the Chinese Academy of Agricultural Sciences estimated that 74% of farmland is P deficient (Zhu and Xi 1990). Second, despite improvements in the P-N ratio in aggregate fertilizer consumption in many countries, not all is well with respect to P fertilizer use, as shown in the next section. Third, in unirrigated regions, where even N fertilizer use has remained low, correction of P deficiency may be crucial to raise returns on the seed, fertilizer, and other dryland technologies. Finally, these reasons gain further strength once we note the role of P at various stages in crop growth and relate it to the historical experiences of countries with sustained growth in yields. In this context, the P constraint seems to have already begun to emerge in a major way in the developing countries of Asia.

Phosphorus constraints and growth of fertilizer use

Since the early 1960s, the developing countries of Asia have raised their fertilizer consumption impressively. Between 1961-65 and 1983-85, total world fertilizer consumption (as aggregate N + P_2O_5 + K_2O) increased from 38 to 128 million t at an average annual rate of 6%. During the same period, total consumption in the developing countries increased from 5 million t to 46 million t at an average annual rate of 10.9% (FAO 1975, 1986). Within the developing world, Asia had the highest growth rate (12%), and its consumption increased from 3 to 37 million t. Thus, in less than three decades, the developing countries of Asia raised their fertilizer consumption to about the same level as total world consumption in the early 1960s—some 120 yr after the use of chemical fertilizers began in the 1840s. About 80% of fertilizer consumption in the developing world in the mid-1980s was in Asia.

Between 1961-65 and 1983-85, the P-N ratio in world fertilizer consumption dropped from 0.85 to 0.48. It declined in both developed and developing countries, from 0.95 to 0.58 in the former and from 0.46 to 0.36 in the latter. Incidentally, the decline in the ratio in the developed world was a correction of the historical trend, since its fertilizer use was dominated by P fertilizers until the 1940s. Within the developing world, the P-N ratio declined from 0.42 to 0.31 in Asia but improved in both Africa and Latin America. Asia, however, had the highest growth rate of P consumption. Thus, the decline in its P-N ratio was due to marginally higher growth rate of N as compared with P consumption (11.5 and 10.1%, respectively).

Asian developing countries

Total fertilizer consumption grew at 13%/annum in both China and India from 1961-65 to 1983-85, although from different base levels (13 kg/ha in China and 3 kg/ha in India). In most other countries, fertilizer consumption grew at an annual rate of more than 10%. Only where the early 1960s levels were relatively high— Sri Lanka, Republic of Korea (ROK), Democratic People's Republic of Korea (DPRK), Vietnam, and the Philippines—did consumption grow at less than 10%/annum.

There were, however, important differences in the relative rates of growth of N and P consumption, and hence in the direction of changes in the P-N ratio. In many countries, P consumption grew more rapidly than that of N, raising the P-N ratio. The improvement in the ratio was modest in India and Indonesia, where it was already above 0.25 in the early 1960s. In other countries like Pakistan, Bangladesh, Burma, Malaysia, and Sri Lanka, where the ratio was relatively low, the improvement was dramatic. On the other hand, in four East Asian countries (China, DPRK, Vietnam, and ROK) and two Southeast Asian countries (Philippines and Thailand), consumption of N grew faster than that of P, and the P-N ratio declined. Thus, the decline in the P-N ratio in developing Asia as a whole was due to the decline in the ratios in these six countries.

This pattern raises an important question: How could the East Asian countries (especially China) continuously raise N consumption, and up to very high levels, without commensurate growth in the use of P fertilizers despite widespread P deficiency? The answer seems to lie in their meticulous management of soil fertility through recycling of OM. Even in the late 1970s, at least 65%, and perhaps as much as 75%, of the substantial quantities of total applied nutrients in China came from organic sources (Stone 1979). Although the contribution of P through OM was relatively low (Zhu and Xi 1990), its massive and meticulous use relaxed the constraints on raising the application of N fertilizers to high levels through effects on soil properties that improve P availability. Thus, the Chinese experience provides a success story in managing alternative P sources and tackling the P constraint in the course of very rapid growth in N fertilizer use (Desai and Stone 1987a).

Thus far, countries outside East Asia have relied mainly on improving the P-N ratio in fertilizer use to manage the P constraint to intensive agriculture. But can this trend continue without adverse impact on both the technical and economic efficiency of fertilizer use? The question is pertinent because most Asian soils are poor in OM content. That recycling of OM is important in sustainable intensive agriculture with high rates of fertilizer use is also clear from the experience of the developed countries (Weber and Gebauer 1986).

It would be naive to assume that the traditions developed over centuries in East Asia could be readily transplanted to other Asian countries. Furthermore, given the high labor requirements of mobilizing, processing, transporting, and applying OM, and also the alternative uses of some forms, the *scale* of the East Asian experience may not be practicable in the developing market economies of Asia. In fact, because of the same reasons, the relative importance of P will most likely increase in the future growth of fertilizer consumption in China and DPRK. Nonetheless, the experiences of the developed world and East Asia stress the complementarity between OM and chemical fertilizers in overcoming soil fertility constraints to sustainable growth in yields.

Three South Asian countries

This section, based mainly on ongoing research at the International Food Policy Research Institute, focuses on the growth of fertilizer use in India, Pakistan, and Bangladesh to highlight certain issues in tackling P and other soil fertility constraints to sustainable yield-based growth.

Fertilizer consumption in each of the 3 countries was 3-4 kg/ha in the early 1960s. By 1985-86 it had increased to about 50 kg/ha in India, 60 kg/ha in Bangladesh, and 75 kg/ha in Pakistan. Although the diffusion of MVs played a key role in all three countries, growth of fertilizer consumption occurred under quite dissimilar conditions (Desai 1988a). For instance, among the three, real prices of both N and P fertilizers (that is, ratios of fertilizer to crop prices) were highest in India and lowest in Bangladesh throughout the period. On the other hand, Pakistan had the highest level of irrigation, and India had relatively better developed physical and institutional infrastructure than Pakistan and Bangladesh. Despite these differences, the growth of fertilizer consumption had similar strengths and weaknesses.

Strengths. First, fertilizer use in all three countries grew on farms of all sizes and under all types of tenurial conditions, although the application rates were often higher on small farms. Second, use was not confined to irrigated areas. Among the three, use on nonirrigated areas was most common in Bangladesh and least common in Pakistan; in India, the pace of fertilizer diffusion under nonirrigated conditions varied widely across locations. Third, the bulk of the growth in use in all countries was for the production of foodgrains (mainly rice and wheat) rather than for high-value commercial crops. Finally, the trends in fertilizer consumption in all three countries were robust and resilient enough to sustain growth despite the shock to the economy of the oil crisis and upward pressures on fertilizer prices.

Weaknesses. Three weaknesses are highlighted: low and infrequent application of OM, persistent geographical concentration of fertilizer use, and slower adoption of P than of N fertilizers.

OM use in South Asia is nowhere near as high and sophisticated as in East Asia. There is insufficient recognition of the fact that, for soils poor in OM, OM use may be too low to sustain growth in yields through fertilizer use alone. Surely, a high proportion of farmers use OM every year, but the quality of OM is generally poor, rates of application are low, and only a small proportion of land receives it.

According to a nationwide survey conducted in India, no more than 38% of the total cropped area received OM in 1976-77 (Table 1). The situation in Pakistan was even worse, with only 22% of the cropped area receiving OM in 1980 (Table 2). In Bangladesh, too, the plots receiving OM typically varied between 25 and 50% for all major crops except aus rice in the late 1970s to early 1980s (BARC-IFDC findings reported by Navin and Khalil 1988). All these findings suggest that a very high proportion of cultivated land receives moderate quantities of OM only once in 3-5 yr. They also suggest that no more than 20-25% of the cropped area in India and 15-20% in Pakistan receive application of both OM and fertilizers in any year. This is unlikely to improve dramatically in the near future, because low

Table 1. Percentage of total cropped area receiving organic manure and fertilizer application under irrigated and nonirrigated conditions in India, 1976-77.

Supplement	Cropped area (%)		
	Irrigated	Nonirrigated	Average[a]
Organic manures			
Farmyard manure	42.03	33.48	35.7
Oilcake	0.94	0.38	0.5
Others	2.37	1.83	2.0
Fertilizers			
$(NH_4)_2SO_4$	11.39	2.26	4.6
Urea	58.33	10.03	22.4
Superphosphate	9.68	2.38	4.2
Others	28.75	6.50	12.2

[a]Weighted average of percentages under irrigated and nonirrigated conditions, weights being total irrigated and nonirrigated area in 1976-77. Source: Government of India (1986).

Table 2. Percentage of area under major crops receiving organic manure and/or fertilizer application in Pakistan, 1980.[a]

Crop	Area (%)					
	M & F	F only	M only	F ± M	M ± F	0
Wheat	16.3	61.3	4.7	77.6	21.0	17.7
Rice	8.0	69.8	2.5	77.8	10.5	19.7
Sugarcane	35.6	52.0	4.4	87.6	40.0	8.0
Cotton	16.6	73.7	2.2	90.3	18.8	7.5
Maize	34.5	29.3	17.1	63.8	51.6	19.1
Potato	33.3	47.6	7.1	81.0	40.5	9.5
Onion	14.7	44.1	11.8	58.8	26.5	29.4
Tobacco	61.0	19.5	9.8	80.5	70.7	9.8
Orchards	33.3	26.5	10.5	59.8	43.8	29.7
Av	17.2	62.3	4.6	79.5	21.7	15.9

[a]M = manure, F = fertilizer, F ± M = fertilizer with or without manure, M ± F = manure with or without fertilizer, 0 = neither fertilizer nor manure. Source: Agricultural Census Organization (1983).

and infrequent application of OM is due mainly to limited availability rather than farmers' attitudes (Jha and Sarin 1981).

To raise soil productivity and generate growth in yields over a long time, use of both OM and fertilizers is crucial. Thus, the above evidence clearly indicates a major problem area. To argue that so far nonuse of OM has not obstructed the growth in yields is not valid for two main reasons. First, the relatively short experience of sustained yield-based growth has been confined to a subset of cultivated land. And second, even here the impact of fertilizer use has been less than expected, and fertilizer use efficiency seems to be declining.

Even after two decades of fairly rapid growth, the top two quintiles of districts accounted for about 60% of total fertilizer consumption in Bangladesh, 77% in India, and 85% in Pakistan during the early to mid-1980s (Table 3). More significantly, the share of the bottom two quintiles of districts was as low as 3% in Pakistan and 7% in India. Only in Bangladesh was it as much as 22%. Given the low and infrequent application of OM, this indicates that growth of yields must be severely constrained by low soil fertility (even with respect to N) in a substantial proportion of cultivated land in all three countries.

That this is indeed true in nonirrigated areas of semiarid tropical regions of India is brought out by the surveys conducted by the International Crops Research Institute for the Semi-Arid Tropics in 10 typical villages of 4 states. In 1983-84, two-thirds of nonirrigated sample farms did not receive any nutrient, either from OM or fertilizers, about one-fifth received OM, and only 9% received both OM and fertilizers (Desai and Singh, unpubl. data). These surveys also reveal that infrequent application of even OM is not confined to mixed crop areas planted to leguminous crops.

The geographical pattern of fertilizer use is associated not only with irrigation and the spread of MVs but also with the degree of development in extension, credit, fertilizer distribution, and output marketing systems. The latter are often

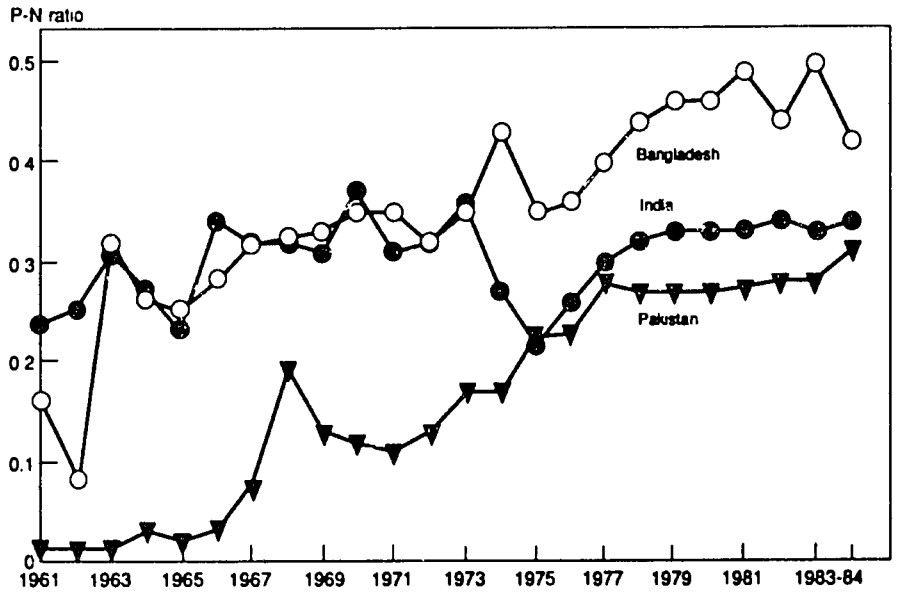
Table 3. Distribution (in percent) of total fertilizer consumption among districts in Bangladesh (average 1982-83 to 1983-84), India (average 1986-87 to 1987-88), and Pakistan (average 1981-82 to 1982-83).

Country	Share of different quintiles of districts				
	I	II	III	IV	V
Bangladesh[a]	37.2	23.0	18.3	13.5	8.0
India[b]	54.3	24.7	13.6	6.1	1.3
Pakistan[c]	56.3	28.2	12.3	3.0	0.2

[a]Derived from Bureau of Statistics (1985). [b]Derived from Fertilizer Association of India (1988). [c]Derived from National Fertilizer Development Center (1986).

more important than the former, as indicated by the evidence from Pakistan, where many districts in the bottom quintiles have more than 25% of their cultivated land under irrigation. Indian data also reveal that many districts with less than 20% irrigation but relatively better development of physical and institutional infrastructure have higher levels and faster growth of fertilizer consumption than those with higher irrigation and even better rainfall environment but poor development of infrastructure (Desai 1985, Desai and Singh 1973, Gujarat Government 1983). Even with high fertilizer subsidies, the degree of development in infrastructure plays a critical role in the geographical pattern of fertilizer consumption in Bangladesh (Ahmed and Hossain, pers. comm.).

The P-N ratio in fertilizer consumption has improved over time in all three countries. But the trends in P-N ratio are still unsteady, and in recent years the ratio fell in Bangladesh (Fig. 1). Furthermore, despite near universal soil P



1. P-N ratio in total fertilizer consumption in India, Pakistan, and Bangladesh, 1961-62 to 1984-85

deficiency, the ratio varies widely across districts, and it was lower than the national average even in many districts with high fertilizer use. Farm level evidence from all three countries also indicates that in high consumption areas many farmers use only N fertilizers.

Surveys carried out by the Indian Agricultural Statistics Research Institute in about 40 districts during the 1970s reveal that the introduction of MVs was soon followed by a rapid adoption of both N and P fertilizers, especially under irrigated conditions. The spread of N use continued, reaching over 80% of cultivated land by the late 1970s at many locations, but that of P began stalling after reaching about 50-60%, even on MVs. On wheat, P use seemed to have picked up after a time lag, but the problem persists with kharif rice. This is confirmed by 1985-86 data from about 1,700 irrigated plots in farmers' fields planted to MVs in Punjab. As many as 35% of plots did not receive P, and the phenomenon was not confined to plots receiving low rates of N, nor to a few districts or blocks of the state. The problem of lower P use is even more serious under nonirrigated conditions. This was brought out by the 1981-82 Agricultural Input Survey of about 25,000 farms conducted in Gujarat. Even in this state, where fertilizer use under nonirrigated conditions is relatively high, substantial spread of P fertilizer on nonirrigated areas was confined to groundnut (Table 4).

Careful empirical research is needed to identify the relative importance of factors behind persistent lower adoption of P than of N fertilizers even in regions of high N use. The lower spread of P fertilizer use is apparently due more to the difficulties in promoting P fertilizers in the absence of sound location-specific

Table 4. Maximum percentage of cropped area receiving N and P fertilizers on various crops, Gujarat, India, 1981-82.[a]

Crop	Cropped area (%)			
	Irrigated		Nonirrigated	
	N	P	N	P
Foodgrains				
Rice	94	31	57	12
Wheat	95	63	32	8
Bajra	86	18	38	18
Jowar (kharif)	34	17	16	10
Jowar (rabi)	65	34	15	2
Maize	81	58	45	20
Gram	55	53	3	2
Nonfoodgrains				
Cotton	89	64	35	14
Groundnut	92	90	79	74
Rapeseed and mustard	84	43	32	3
Castor	[illegible]	22	20	7
Sugarcane	99	96	53	41
Tobacco	99	4	87	11

[a]Source: Gujarat Department of Agriculture (1984).

research on optimal fertilization than to uneconomic response to P fertilizers (Roy and Kanwar 1979, Tandon 1987).

Implications of weaknesses. The most important consequence of low and infrequent OM application, persistent geographical concentration in fertilizer use, less common use of P than of N fertilizer, and many other deficiencies in fertilizer practices (like inappropriate timing, placement, and method of application; and general absence of soil tests in deciding application rates) has been the less-than-expected impact of growth in fertilizer use on crop production. The application rates of N fertilizers at many locations have reached much higher levels than indicated by the averages for the country or even for provinces, states, or districts. Continued dependence on a subset of cultivated land for growth in fertilizer use (often because of infrastructure and institutional constraints) has already started generating pressure for larger fertilizer subsidies and higher support prices for crops (Desai 1986, 1988b).

Conclusion and important policy issues

During the last two decades, the developing countries of Asia have come a long way in introducing two major factors needed for yield-based agricultural growth, namely crop varieties with high yield potential, and fertilizer. This has paid off by breaking the yield barriers in most major crops. But to raise production to the levels needed in the future, major obstacles still exist. Among these, soil fertility constraints are crucial.

Fertilizers have become increasingly important in raising yields, but there are still major deficiencies in policies and efforts to tackle soil fertility constraints through fertilizers. Two aspects deserve particular attention: 1) broadening of the geographical pattern of fertilizer consumption within countries, and 2) balanced use of fertilizers containing different nutrients, especially N and P. Both are equally important for yield-based growth in the entire agricultural sector, and also to sustain efficiency over a long period.

Neither of the two aspects can be effectively dealt with through fertilizer subsidies alone. Favorable price environment is a necessary but not sufficient condition. Similarities in the experiences of India, Pakistan, and Bangladesh, with their significant differences in price environment, point this out. Whether in India, where prices have been less favorable than in many other countries, or in Bangladesh, where they have been quite favorable, the most binding constraints to the geographically broad-based growth of fertilizer use and balanced application of different fertilizers are in the domain of nonprice factors (Desai 1986, 1988b; Stone 1987). These can be divided into three broad categories: 1) location-specific research on soil fertility constraints, agronomic practices, etc. and effective use of research results in extension activities; 2) adequate development and efficient implementation of agricultural credit as well as fertilizer supply and distribution systems; and 3) development of physical and institutional infrastructure. Numerous deficiencies in these matters in the developing world are generally known. Removal of these deficiencies is more crucial than price incentives through budgetary subsidies to tackle effectively the two problem areas mentioned earlier.

To deal with the P constraint, the nonprice factors cited are equally if not more important. A wide variety of factors affect responses of crops to P, and their relative importance differs across locations. Location-specific research and an effective soil testing service are crucial to generate the knowledge farmers need to use fertilizer. Similarly, timely supply of the right type of P fertilizer is crucial, since such fertilizers are needed for basal application under a variety of soil conditions. This calls for a well-developed fertilizer distribution system and its effective interface with local research and extension machinery. Given the high dependence of Asian less developed countries on imports of P fertilizers and their raw materials, removal of the deficiencies in the aggregate fertilizer supply system is also more important in the case of P than in that of N (Desai and Stone 1987b).

The problem of low and infrequent OM use also deserves attention. Vigorous and sustained efforts are required to create awareness among both policymakers and farmers of the relationships between OM use, soil properties, and fertilizer use efficiency. The real question is not just the relative cost of supplying nutrients through OM versus fertilizers. It is whether, and with what efficiency, growth in fertilizer use alone can maintain the required growth in yields on soils poor in OM.

Thus, to sustain yield-based growth in Asian agriculture, a new orientation in policies is needed. So far these policies have been governed mainly by the N constraint and the desire for a rapid impact of fertilizers on food production to lower food imports. These policies should be increasingly guided by the persisting N constraint on a substantial proportion of cultivated land, the emerging constraints with respect to P and other nutrients, and the long-term implications of low OM use for soil properties and fertilizer use efficiency in raising yields.

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Notes

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Acknowledgment The authors are grateful to Mrs. Suman Rustagi for research assistance in preparing this paper.

Citation information International Rice Research Institute (1990) Phosphorus requirements for sustainable agriculture in Asia and Oceania P O Box 933, Manila, Philippines.