Chapter 7.
PHOSPHORUS LIMITATIONS AND MANAGEMENT CONSIDERATIONS

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Phosphorus is undoubtedly one of the most severely limiting elements in the acid, infertile soils of tropical Latin America, as shown by Maps 17 and 18 (see Map Plates). Total P ranges from only about 200 to 600 ppm and available P (Bray 11) from I to 7 ppm. It is obvious that, to efficiently increase crop production, phosphate fertilizer must be added to these soils and plant species that are efficient P users must be selected. Because of the acid reaction of most soils in the region (pH 4.0-5.5), some soils, especially in the central savanna area, are high in free Fe and Al oxides and hydroxides which tend to rapidly fix large amounts of P (Map 19). This is especially so when it is applied in soluble forms such as monoammonium phosphate (MAP), diammonium phosphate (DAP), single superphosphate (SSP), or triple superphosphate (TSP) (Fenster and Le6n, 1979).

To develop a sound, economic P-management strategy for pastures and crops grown on the acid, infertile soils of tropical Latin America, several strategies might be taken into consideration. These include but are not necessarily limited to: (1) use of cheaper, less-soluble forms of P such as phosphate rock (PR) or partially acidulated PR; (2) use of soil amendments to enhance the availability of soil-applied P; (3) determining optimal placement and rates of P fertilizer to increase its efficiency, both initially and residually; and (4) selection of plant species that will tolerate relatively low levels of available soil P.

Cheaper, Less Soluble Sources of P

The use of phosphate rock (PR) as a P source for crop production appears both economically and agronomically attractive for much of the region. Not only is the unit cost of the P much lower-one-third to one-fifth that of TSP or SSP (IFDC, 1979)-but also the residual value of the product is likely to be equal to or greater than that of the more soluble P carriers. Since continuous dissolution of PR can occur in acid soils, it is likely that release of available P will be more in unison with the requirements of growing forages which are predominant in much of the region.

Due to the high requirement for P, and especially following the sharp increase in phosphate rock prices during 1974-1975, there have been intensified exploration efforts that have identified new phosphate resources. The most significant of these developments has occurred in Brazil where about I X 10' tons/year are now being produced from igneous deposits at Jacupiranga, Araxa, Tapira, and Cataldo (G. H. McClellan, IFDC, pers. comm., 1979). There are over 20 major deposits located in tropical Latin America (Figure 7-1).

The International Fertilizer Development Center (IFDC) has developed a research program on phosphates, which is strongly oriented toward identifying methods for using these resources. Much of the agronomic research on phosphates in Latin America has been conducted in cooperation with CIAT (Centro Internacional de Agricultura Tropical) in Cali, Colombia. The aim has been to select, adapt, or develop technology that is the most cost effective for meeting the needs of agriculture with the resources (raw materials, energy, infrastructure, etc.) at hand. This approach involves developing or identifying phosphate fertilizers that are well suited to tropical and subtropical soils in agronomic, technical, and economic aspects. Application or adaptation of conventional technology may or may not be the best choice.

Direct application of finely divided phosphate rock may be one of the cheapest ways to supply P to crops in many acid soil areas in the tropics and subtropics. The degree to which direct application will be effective is determined by a number of interrelated factors. These include, but are not limited to: (a) the reactivity, or potential, of the rock source as determined by the chemical composition of the apatite; (b) the physical properties of the rock; (c) the properties of the soil (acidity, available P, exchangeable Ca in the soil, and P-sorption capacity); (d) the type of crop and cropping system; (e) the method of application; and (f) the time of reaction (Parish et al., 1980).

Chemical Reactivity of Phosphate Rocks

Many Oxisols and Ultisols possess properties conductive to the dissolution of directly applied ground phosphate rock. They are acid; some of them possess high P-sorption capacity; and they generally exhibit only low concentrations of P in the soil solution and exchangeable Ca in the soil. Still, the effectiveness of each potential rock source for direct application will be determined by the chemical reactivity of the phosphate rock. It has been shown that the reactivity depends on the degree of carbonate substitution for phosphate in the apatite structure (Lehr and McClellan, 1972); several solubility tests are suitable for estimating reactivity. These include extraction with neutral ammonium citrate, 2% citric acid, 2% formic acid, and acid ammonium citrate at pH 3 (Chien and Hammond, 1978). Based on these measurements, it has been possible to categorize phosphate rocks into relative

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rankings of high, medium, or low potential for direct application. Based on agronomic evaluation of phosphate rock from 18 separate deposits around the world, it can be generalized that rocks with citrate-soluble P greater than 17% of the total P can be ranked as having a high potential for direct application. Those with 12-17% citrate-soluble P would be considered in the medium range, while rocks with less than 12% of the total P being citrate soluble would be expected to perform relatively poorly when compared to the initial crop response possible with water-soluble P fertilizers or the highly reactive phosphate rocks.

Fig. 7-1 Locations of 20 phosphate deposits in Latin America.

Figure 7-2 illustrates these differences with results from a short-term greenhouse experiment with P supplied by a number of rocks from South America. While some rocks performed nearly as well as TSP, a large range in effectiveness can be observed. Depending on soil properties, crop type, and management, finely ground rock with high, medium, and low citrate solubilities generally has effectiveness ranges of 80-1 00. 50-80, and 30-60%, respectively, when compared to the initial crop responses to TSP. Recent studies on residual value of phosphate sources show that, even for the low-reactivity rocks in some soil-crop combinations, the initial differences between sources diminish with time. Table 7-1, in fact, shows that there has been significant response to P but no difference between sources in total yield of *Brachiaria decumbens* following 4 years of production, despite the fact that yields during the first cutting followed the levels predicted by citrate solubility. Research has also shown that dustiness, one of the main objectionable properties of phosphate rock, can be eliminated without loss of effectiveness when granulated or "minigranulated," as it is called, to a size range of 50 to 150 mesh (Tyler screens). These minigranules are consistently equal to or nearly as effective as powdered rock. In contrast, conventional granulation (6- to 16-mesh [Tyler] granules') substantially reduces the agronomic effectiveness of the rock.

Partial Acidulation of Phosphate Rock

In some situations there is a need for a phosphate fertilizer intermediate in water solubility between directly applied, finely ground rock and conventional, fully acidulated fertilizers. This need is most apparent where the reactivity of available phosphate rock is too low to provide the P requirements of plants for rapid establishment or for crops with a short growing season. Partially acidulated phosphate rock (PAPR) is an alternative that may fill this gap and can be especially important to some developing countries, which have rock deposits but only a limited availability of acid for production of conventional fertilizers.

In recent studies it has been observed that phosphoric acid (H_3P0_4) is highly effective in increasing the initial P availability of low-reactivity phosphate rocks, using only 10-20% of the amount necessary to make triple superphosphate (Hammond et al., 1980). With the Pesca PR from Colombia, for example, 20% acidulation with H_3PO_4 was observed to be 79-90% as effective as TSP in a greenhouse experiment, whereas the unacidulated rock was only 10% as effective. Using sulphuric acid, 40-50% of the H_3S0_4 required to make single superphosphate may be required to be equally as effective as the material treated with 10-20% H_3PO_4- It is promising, therefore, that fertilizer prepared with less than the conventional quantities of acid can be a highly effective means of supplying P. The use of indigenous phosphate rock as a direct application material, or when processed by both conventional and nonconventional technologies, is being studied. Only careful agronomic, industrial, and economic evaluations will give the correct routes for utilization of these phosphate rock deposits; but the potential saving in terms of foreign exchange for many developing countries is such that these studies are a much needed activity.

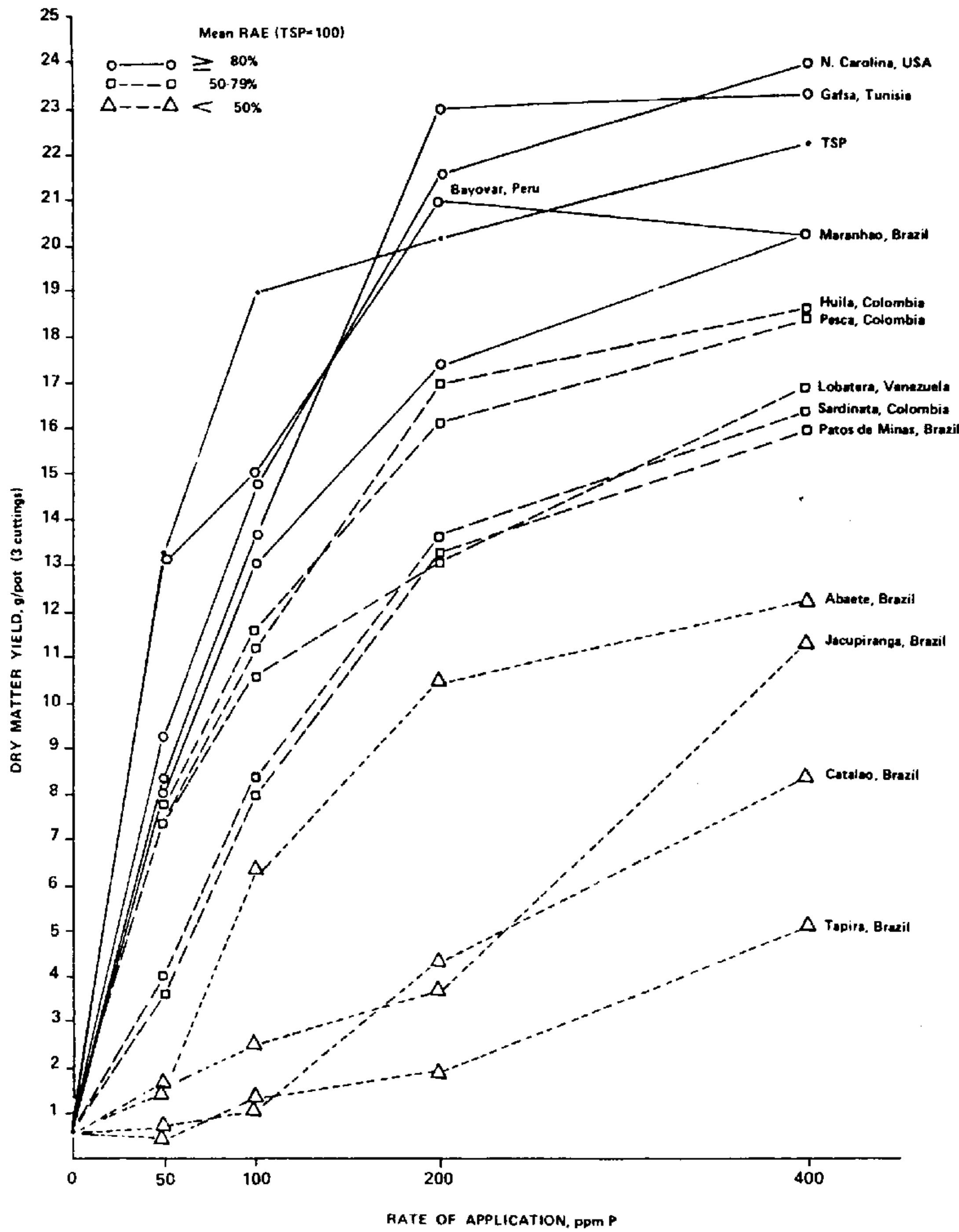

Fig. 7-2 Greenhouse comparisons of various phosphate rocks using *Panicum maximum* as the test crop. Source: Adapted from CIAT Annual Report (1979).

Table 7-1. Effect of phosphorus sources and levels (% of TSP residual) on relative yield of *Brachiaria decumbens* grown in the field on a Carimagua Oxisol Colombia (sum of 14 cuttings).

Phosphorus source	P_2O_5 added[a] 25 kg/ha	50 kg/ha	100 kg/ha	400 kg/ha
Triple superphosphate (TSP)				
Annual	(33.6)	(35.9)	(37.4)	(45.2)
Residual[b]	100	100	100	100
	(22.0)	(30.6)	(32.4)	(38.1)
Phosphate rock (PR)				
Fosbayovar	119	80	102	109
Florida	122	94	100	105
Gafsa	109	103	104	104
Huila	95	113	98	110
Pesca	111	81	111	116
Tennessee	104	76	95	108
Check (14.4)				

a. Figures in parentheses are dry matter yield (t/ha).
b. TSP residual considered as 100% at each P_2O_5 rate.

Table 7-2. Decrease in P fixation due to lime and silicate applications sufficient to neutralize exchangeable Al in a clayey Oxisol from Brazil with an original pH of 4.6, 1.45 meq Al/100 g soil and 80% Al saturation.

Amendment applied	P fixed (ppm) to give .03	.10	.20	Decrease (%) in P fixed .03	.10	.20
	(ppm P in solution)			(ppm P in solution)		
None	230	325	415	-	-	-
Lime (1.5 t/ha)	135	275	370	41	15	11
Calcium silicate (1.8 t/ha)	125	265	355	46	18	14

SOURCE: Adapted by Sánchez (1977) from Smyth (1976).

Soil Amendments to Enhance the Availability of Soil Applied P

One of the problems encountered with some of the P deficient, acid, infertile soils of tropical Latin America is their high P-fixation capacity (see Map 19). To decrease this fixation capacity, soil amendments, such as lime or Ca silicates, are sometimes applied. It is important here to note that the concept of adding lime to increase production through utilization of the native P in the soil is probably erroneous in the acid, P-deficient soils of tropical Latin America since the total amount of P in these soils is so low. The concept of adding lime to increase or maintain the availability of applied P, however, has merit.

For example, a greenhouse experiment was conducted using a Carimagua Oxisol, in which varying rates of P were applied with combinations of Ca silicate, lime, and Mg oxide (CIAT, 1977). In all cases, the addition of one or more of the amendments significantly increased the yield of *Stylosanthes guianensis* (two cuttings) over that of TSP applied alone. The highest yield was obtained with TSP plus additions of Mg oxide and Ca silicate.

The main problem encountered with many of the P amendment experiments is determining if the lime or Ca silicate is enhancing the availability of the applied P or whether there is an additional lime and/or nutrient response. On these acid soils, Ca and Mg deficiencies are common, so the additions of amendments may very well be responses to these cations. Research by Smyth (1976) in Brazil would indicate, however, that there is definitely an amendment effect of decreasing P fixation from both the lime and Ca silicate (Table 7-2).

Placement and Rate of P Fertilizers

Placement of phosphorus. In tropical Latin America, P fertilization of pastures has generally followed the classical approach of broadcasting and incorporating basic slag or superphosphate during establishment, followed by periodic top-dressing. Recently, however, some research has been conducted to ascertain the effect of P placement on establishment of pasture and annual crops (Le6n and Fenster, 1979).

Preliminary results from a continuing experiment at the Quilichao experiment station near Cali, Colombia (Fenster and León, 1979) indicate that broadcasting P is superior to banding in growing *Panicum maximum and Andropogon gayanus* pastures (Figure 7-3). Nevertheless, in this same experiment, broadcast plus band application of P gave the highest yields. This would suggest that banding is important in establishing these pastures, but broadcast treatments are necessary for maintenance.

It is also probable in very low P-supplying soils, that when only banded P is applied, root growth is restricted to the band area; thus the plants are susceptible to drought, even during short periods when it does not rain. Short periods of drought are common in many Oxisols and Ultisols because of their low water-holding capacity.

In another experiment initiated by Le6n and Fenster(1979) *with Brachiaria decumbens* at Quilichao, the highest yields were realized with 100 kg P20,/ha of TSP broadcast and incorporated. In this case, broadcast and incorporation of the TSP was superior to other methods of application. When a basal treatment of 100 kg P105/ha as phosphate rock was broadcast and incorporated, however, there was no difference in yield due to method of application of TSP. Nevertheless, yield increases due to P levels were evident. For the establishment of *Brachiaria decumbens,* it apparently is not necessary to apply more than 50 kg P205/ha as TSP. Long-term experiments by Yost et al. (NCSU, 1973, 1974, 1975) with corn at the Cerrado Center Station near Planaltina in Central Brazil indicate that a combination of broadcast plus bandplaced P is the most promising strategy.

Rates of phosphorus. Several experiments have been conducted with a number of crops to determine the P rates necessary to maximize production, but only one is discussed in this section.

Hammond and Le6n (CIAT, 1977) established an experiment on a Carimagua Oxisol in Colombia (land system No. 20 1) *with Brachiaria decumbens* using rates of 25, 50, 100, and 400 kg P20,/ha as TSP. Figure 7-4 shows the response of this grass to different levels of phosphorus. This experiment is showing good residual effect of the soluble phosphorus applied initially. Fertilization after the first year, with the same P levels as a maintenance application, would appear reasonable only for the 25 kg P20,/ha treatment, where the yield increase was more than 4 ton/ha. It is not considered necessary to use annual applications of 50 kg P205/ha or more, because yield increases due to these treatments are only of the order of 2 ton/ha.

Although the P-fixation capacity of these Oxisols is appreciable, it is not as high, for example, as in the case of the Andepts and some Oxisols from Brazil. This in part explains why the forage grasses yielded so well at lower P rates than did forage yields from experiments carried out in the Cerrado Center, Brazil (Fenster and Le6n, 1979).

There is a good initial plant response to soluble forms of added phosphorus in many Oxisols. The residual effect, however, depends upon both the mineralogical and chemical characteristics of a soil as well as the test crop itself.

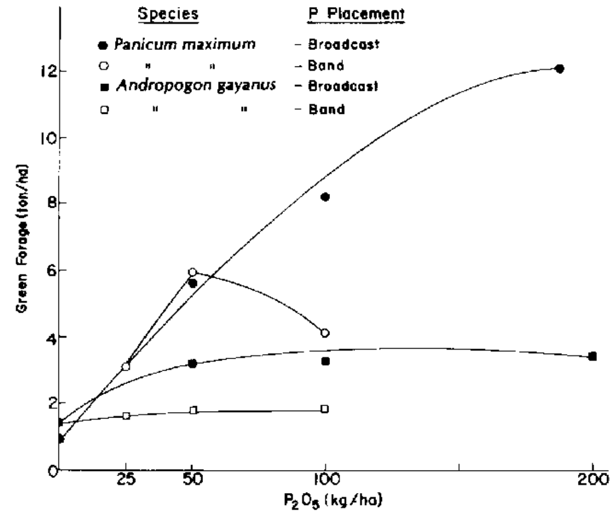

Fig. 7-3 Effect of rates and method of application of phosphorus (TSP) on two grasses grown on a CIAT-Quilichao Ultisol. Source: Unpublished data by Sánchez et al. (1978).

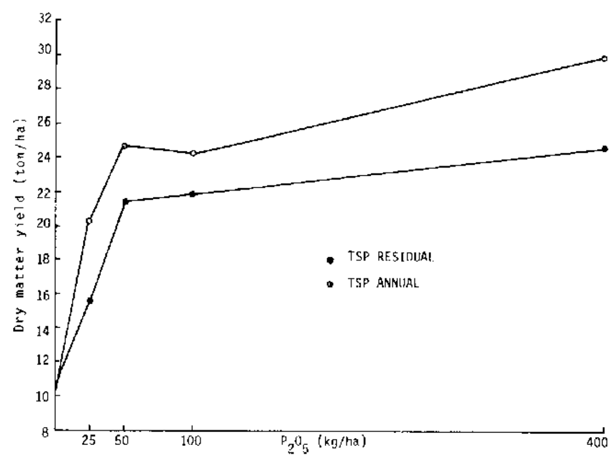

Fig. 7-4 Phosphorus response of *Brachiaria decumbens* grown on a Carimagua Oxisol (sum of eight harvests). In the annual treatment, P was reapplied 1 year after planting.

Selection of Plant Species Tolerant to Relatively Low Levels of Soil P

According to several researchers (Ozanne et al., 1969; IRRI, 1972; Salinas and Sánchez, 1976; CIAT, 1978a, 1980a), species or varieties that are tolerant to low levels of P produce maximum yields at lower levels of applied P than do the sensitive species or varieties.

Salinas and Sánchez (1976) present a literature review on differences among species and varieties in relation to low levels of available P in the soil. There is evidence of appreciable difference among species with respect to the external and internal critical levels of P. The most tolerant annual crops and tropical pastures to low levels of P are rice, cassava, sweet potatoes, corn, *Stylosanthes humilis, Stylosanthes guianensis, Stylosanthes capitata, Centrosema pubescens, and Andropogon gayanus.* Four mechanisms are cited by Salinas and Sánchez to explain these differences: root extension, root exudation, influence of mycorrhiza fungi, and the differences in P absorption and translocation rates in relation to growth rates.

There is some limited evidence suggesting that tolerance to high Al saturation and low P may occur together in some species in acid soils. A faster translocation rate of P in the roots to the top and Ca translocation seem to be the main factors accounting for these differences.

Conclusion

Increase in food production due to correction of P deficiency in the acid tropical soils of Latin America can be achieved through a number of approaches. The chemistry of fertilizer reactions in these soils is not unique and, therefore, conventional fertilization practices can be expected to be satisfactory from an agronomic point of view. In the region described in this book, however, major limitations to standard approaches are frequently encountered due to the scarcity or high cost of soluble phosphate fertilizers. In those conditions, significant yield increases can be achieved with substantially reduced cost through the use of low-cost fertilizer sources, such as finely ground phosphate rock; the use of adequate placement and rates of P fertilizers together; and, where practical, the selection of plant species tolerant to low P levels.

While it is generally accepted that P is the most limiting plant nutrient in the region, full benefit from investment in phosphate fertilizer, regardless of source, can only be sustained with a complete fertilizer management strategy. Once the rate of plant growth is increased by relieving the phosphorus limitation, the increased uptake of N, K, Ca, Mg, S, and micronutrients must also be compensated.