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MANAGEMENT OF PHOSPHORUS FERTILIZATION IN ESTABLISHING AND MAINTAINING IMPROVED PASTURES ON ACID, INFERTILE SOILS OF TROPICAL AMERICA

William E. Fenster
Luis Alfredo León*

ABSTRACT

One of the major problems in establishing and maintaining improved pastures, in the Oxisols and Ultisols of tropical Latin America, is the extremely low levels of both total and available P. In addition, these soils generally have a high P fixation capacity so substantial amounts of P must be added to satisfy both the plant and the soil requirements. Because of these constraints, along with the high unit cost of P fertilizers, alternative methods of managing improved pastures must be considered. This paper considers four economical methods of improving forage production while still satisfying the P requirements of the plant. These are: (1) selection of plant species that will tolerate relatively low levels of available soil P; (2) determining rates and placement of P fertilizers to increase their efficiency, both initially and residually; (3) use of cheaper and less soluble forms of P carriers; and (4) use of soil amendments to enhance the availability of soil applied P.

Phosphorus is generally considered the most limiting element in the acid, infertile soils of tropical Latin America. Total P will range from only about 200 to 600 ppm and available P, determined by the Bray II method, from 1 to 5 ppm. It is quite obvious that to increase forage production phosphate fertilizer must be added to these soils and plant species that are efficient P users must be selected. These soils are acid (pH 4.0-5.5), and often high in free Fe and Al oxides and hydroxides which tend to rapidly fix large amounts of P, especially when it is applied in soluble forms such as simple (SSP) or triple (TSP) superphosphate.

* Soil Fertility and Soil Chemistry Specialists, respectively. Members of the International Fertilizer Development Center, Phosphorus Program, stationed at Centro Internacional de Agricultura Tropical, Cali, Colombia.

Although P is highlighted in this paper on forage production, it must also be remembered that these soils are generally deficient in all of the primary and secondary nutrients as well as Zn, B, Mo, and Cu (12). In addition, there are also many instances of Mn and Al toxicities affecting a number of the forage species.

From a physical properties standpoint Oxisols and Ultisols present few management problems. With the exception of some of the sandy Ultisols, which are susceptible to mechanized compaction and erosion, these soils have excellent structure, are generally well drained, and have good water infiltration capacity. Sánchez (11) states that, "the excellent structure of these soils is caused by primary particles being aggregated in very stable sand-sized granules. Their high stability is associated with high clay content and cementing or coating of amorphous iron and aluminum oxides". Because of the stable sand-sized particles, the water holding capacity of these soils is relatively low and even during short periods of drought, plant water stress can be a problem.

In order to determine a sound, economic P management strategy for forages grown on the acid, infertile Oxisols and Ultisols of tropical Latin America, several factors must be taken into consideration. These would include but not necessarily be limited to: (1) selection of plant species that will tolerate relatively low levels of available soil P, (2) determining rates and placements of P fertilizer to increase its efficiency, both initially and residually, (3) use of cheaper, less soluble forms of P such as phosphate rock (PR) or partially acidulated PR, and (4) use of soil amendments to enhance the availability of soil applied P (12).

USE OF EFFICIENT FORAGE SPECIES AT LOW LEVELS OF AVAILABLE SOIL PHOSPHORUS

Muller (2) conducted a greenhouse experiment on a Carimagua Oxisol with several forage species to determine the critical P soil test level for obtaining 60 to 80% of maximum yield, according to the Cate-Nelson method. Levels of soil applied P ranged from 0 to 240 kg/ha and dry matter (DM) yields were correlated with soil test P values (Bray II) to estimate external P requirement. The results indicate that the external P requirement varied markedly between the forage species and ecotypes tested (Fig. 1). The range was from 2.5 ppm P for ecotypes of *Stylosanthes guianensis* (Aubl.) Sw. and *Stylosanthes capitata* Vog. to 11.4 ppm P for *Desmodium leonii.* Unpublished data by León indicate that rates of applied P would vary from approximately 50 to 300 kg P_2O_5/ha, to accommodate this range of plant requirements in an Oxisol from Carimagua and an Ultisol from Quilichao, in Colombia (Fig. 2).

Sánchez, León and Ayarza (unpublished data) working with several legume species planted on the Quilichao Ultisol in the greenhouse, show a wide variety of yield responses to added P. In general *Centrosema plumieri* (Pers.) Benth., *Zornia* 728, and *S. capitata* did not respond to added P, whereas *S. guianensis* 136, *Desmodium ovalifolium* Vahl. and *Centrosema* 1733 responded to levels of 50, 100 and 400 kg P_2O_5/ha, respectively (Fig. 3). These data appear to correlate well with those of Muller and of León (Figs. 1 and 2).

When taking into consideration the minimum input philosophy it is significant that only 50 kg P_2O_5/ha is needed to achieve the lowest critical soil test level of 2.5 ppm P (Bray II) for *S. capitata* in Carimagua. It is also important to realize that this minimum input level will probably have very little residual value so consideration should be given to either applying a higher rate of P initially or annual applications later. In order to sustain even the most P efficient species it would appear that substantial amounts of fertilizer P are required.

Another aspect to consider in selecting forage species with relatively low P requirements is the amount of P needed to establish the pasture versus the amount needed to sustain it at near maximum yield levels. Ozanne *et al.,* (10) conducted a pot experiment with eight different legume and grass species, adapted to Australian conditions, in which they determined the P requirements at different stages of growth. The minimum amount of P required for 90% of maximum growth varied markedly with stage of growth within species and between the various species (Table 1). In general, however, with the exception of one legume *(Trifolium cherleri* L.), the minimum P requirements for near maximum growth at maturity were equal to or less than the initial plant requirements.

In selecting a low P tolerant forage the ideal situation would be a plant species that has both low initial and maintenance P

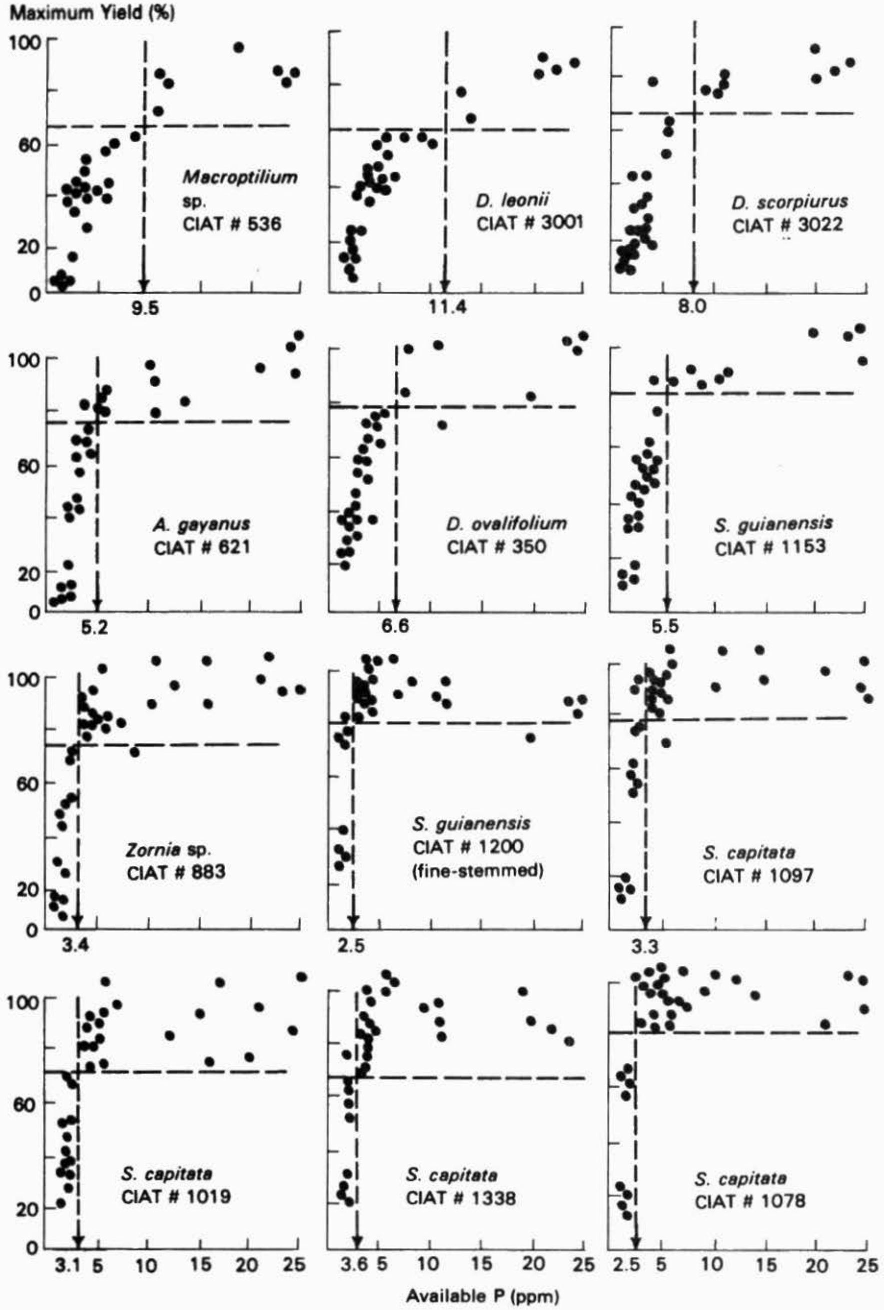

Figure 1. **External P requirements of 12 CIAT accessions grown on a Carimagua Oxisol, in the greenhouse (3).**

requirements. In the absence of this, however, a reasonable alternative would be to select a forage that may require somewhat higher amounts of P in establishment but only minimal amounts for maintenance.

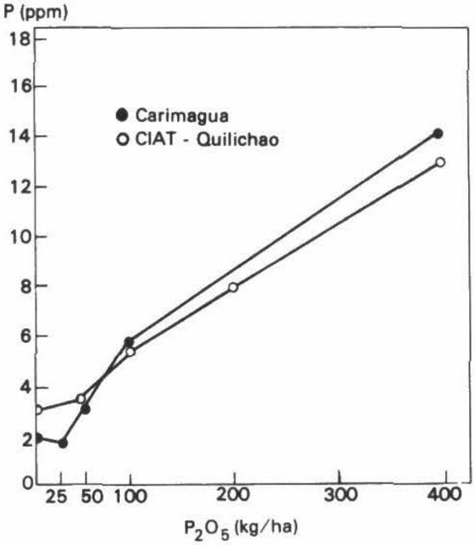

Figure 2. **Effect of phosphate (TSP) additions on soil test phosphorus (Bray II) from two locations in Colombia.**

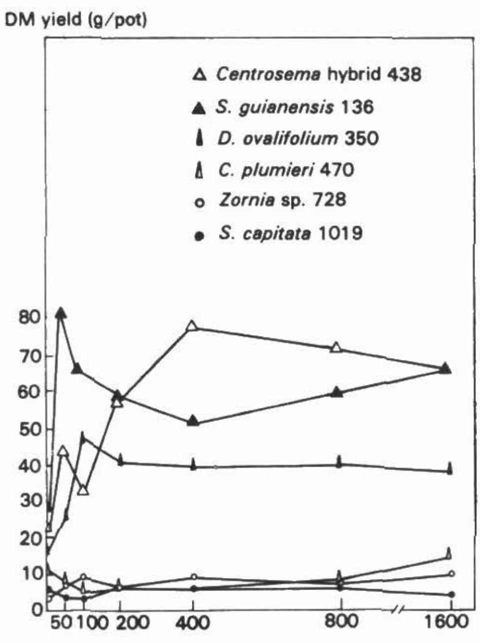

Figure 3. **Effect of varying levels of P (TSP) on DM yields of several forage legumes grown in the greenhouse on a CIAT-Quilichao Ultisol. (Unpublished data by Sánchez *et al*).**

Table 1. **Phosphorus required for 90% of maximum yield of tops at two harvest times in Australia. (Adapted from 10).**

Species	P applied ppm Day 29	Day 92*
Trifolium cherleri	140	302
Trifolium hirtum	128	124
Trifolium subterraneum	137	87
Lupinus pilosus	49	57
Cryptostemma calendulacea	242	43
Erodium botrys	124	43
Lolium rigidum	80	26
Festuca myuros	87	21

* Full flowering

DETERMINING MOST EFFICIENT PLACEMENT METHODS AND RATES

Placement

In tropical Latin America P fertilization of pastures has generally followed the classical approach of broadcast and incorporation of superphosphate during establishment, followed by periodic topdressings. Recently, however, some research has been conducted to ascertain the effect of P placement on pasture establishment and the results have varied markedly.

Spain and Ayarza (2), using basic slag as the P source, compared broadcast versus band applications on three grass-legume mixtures in a field experiment at Carimagua, Colombia. The comparison also included levels of 10, 40 and 70 kg P_2O_5/ha and the seeds were mixed with the fertilizer, so in effect seeding was also banded or broadcast. They concluded that there was a definite advantage to banding the seed and fertilizer application (Fig. 4). Band placement also appeared to benefit the legume more than the associated grass. They concluded that, "band seeding and fertilizer applications

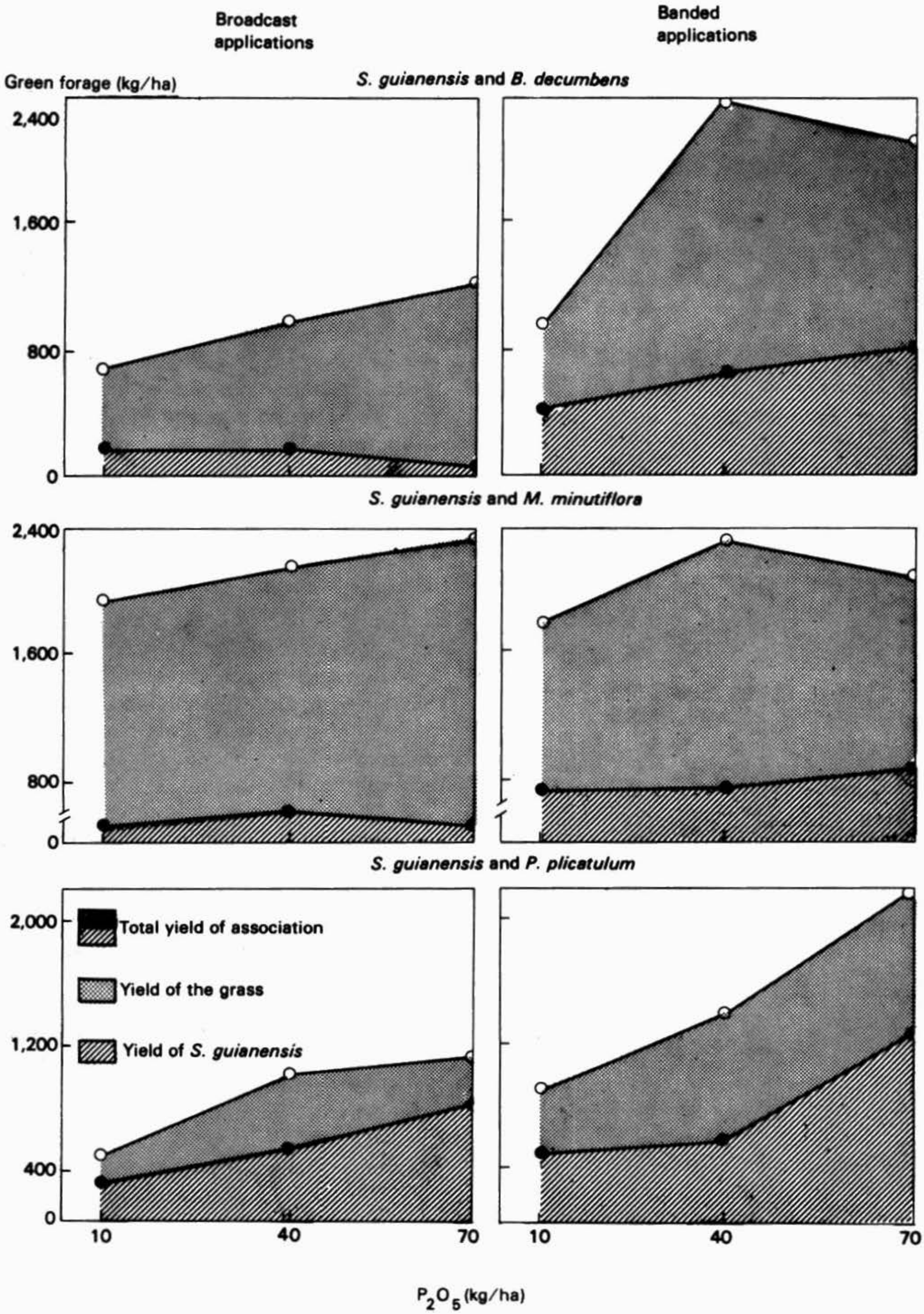

Figure 4. Effect of three levels of P and method of application on yields of three forage associations on a Carimagua Oxisol (2).

apparently create a more favorable fertility environment for the developing seedling than do broadcast applications. The fertilizer is concentrated in the seedling zone and phosphorus availability is greater during the seedling stage when it appears to be especially critical for small-seeded forage species".

Preliminary results from a continuing experiment being conducted by Sánchez, Ayarza and León, at the Quilichao experiment station in Colombia, indicate that broadcasting P is superior to banding in establishing *Panicum maximum* Jacq. and *Andropogon gayanus* Kunth. Results of selected TSP treatments on yields of these two grasses are illustrated in Figure 5. In this same experiment broadcast plus band application of P gave the highest yields. These preliminary data would suggest that banding is important in establishing the forage but broadcast treatments are *necessary for maintenance.*

It is also probable in these 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

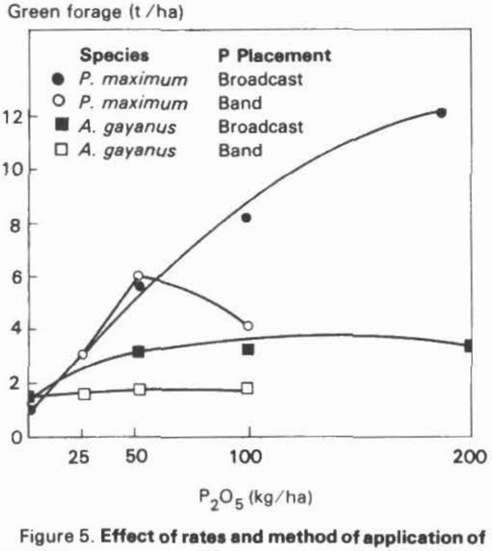

Figure 5. **Effect of rates and method of application of P (TSP) on two grasses grown on a CIAT-Quilichao Ultisol. (Unpublished data by Sánchez *et al.*, 1978).**

drought, even during short periods when it does not rain (7, 8, 9). Short periods of drought are common in many of these Oxisols and Ultisols because of the very stable sand-sized aggregates at the surface (7, 8, 9).

It is obvious that more research is needed to ascertain the merits of P placement in pasture production. These experiments should be relatively long-term so residual values of the P placement can also be studied. Long-term experiments by Yost *et al.* (7, 8, 9) with corn at the Cerrado Center in Brazil, indicate that a combination of broadcast plus banded P is the most promising strategy.

Rates of phosphorus

Several experiments have been conducted in tropical Latin America with a number of forage grass and legume species to determine the P rates necessary to maximize pasture production. Although many of these experiments have included several P carriers, only SSP and TSP will be discussed in this section.

In the Cerrado of Brazil, North Carolina State University and Cornell (7) initiated a long-term P experiment with *Brachiaria decumbens* Stapf. using 86, 345 and 1380 kg P_2O_5/ha as SSP as basal rates. Although the 1380 kg/ha treatment yielded somewhat higher the first two cuttings, the 345 kg P_2O_5/ha treatment was giving comparable results after the third harvest (Fig. 6). Hammond, León and Gualdrón (3) established a similar experiment on a Carimagua Oxisol in Colombia with *B. decumbens* using 25, 50, 100, and 400 kg P_2O_5/ha as TSP. In this instance it would appear that the 100 kg P_2O_5/ha treatment, is comparing favorably with the 400 kg/ha treatment (Fig. 6).

These two continuing experiments are a good illustration of why it is so difficult to make generalized phosphate recommen-

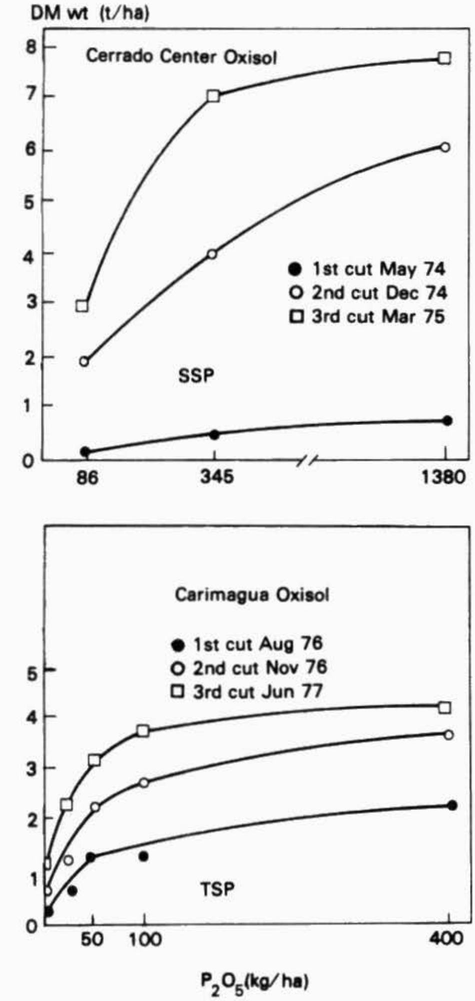

Figure 6. **Effect of varying rates of P on DM yield of *B. decumbens* at two locations. (Adapted from 3 and 8).**

dations on forages of tropical Latin America. Here is a situation where the same grass species was grown on two different P deficient Oxisols and the P requirements for maximizing production differ by approximately three orders of magnitude. León and Sánchez (3) found the P fixation capacity of these two soils to vary quite markedly. It took additions of 350 and 750 ppm P for the Carimagua and Cerrados soils, respectively, to reach a level of 0.2 ppm P in the soil solution (Fig. 7). The differences in the P fixation capacities of these two soils probably explain, to a large degree, why the P requirements for forages vary so markedly from place to place. This also emphasizes the point that both the plant requirements and the soil chemical characteristics must be understood in order to make reasonably accurate fertilizer recommendations.

Spain (3), in another pasture experiment at Carimagua with four grass species and varying rates of P_2O_5, found significant yield responses to all levels of applied P. The biggest response, however, was noted at the 50 kg P_2O_5/ha rate for all species except *Hyparrhenia rufa* (Nees) Stapf. which responded linearly up to 100 kg P_2O_5/ha (Fig. 8). These results are an average of three or four harvests during the first year after establishment. Similar results have been observed by Sánchez, León and Ayarza (3) in a greenhouse trial with *P. maximum* and a *Centrosema* hybrid 1733, on a Quilichao Ultisol. The first inflection point on the response curve was at about 40 kg P_2O_5/ha for the *Centrosema* hybrid and 60 kg/ha for *P. maximum* (Fig. 9).

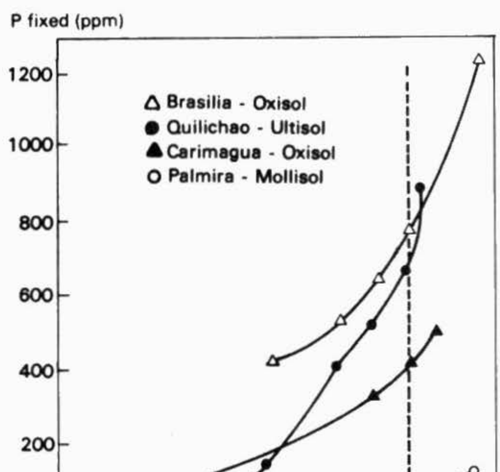

Figure 7. **P fixation isotherms of CPAC-Brasilia, CIAT-Quilichao, CNIA-Carimagua, and CIAT-Palmira (3).**

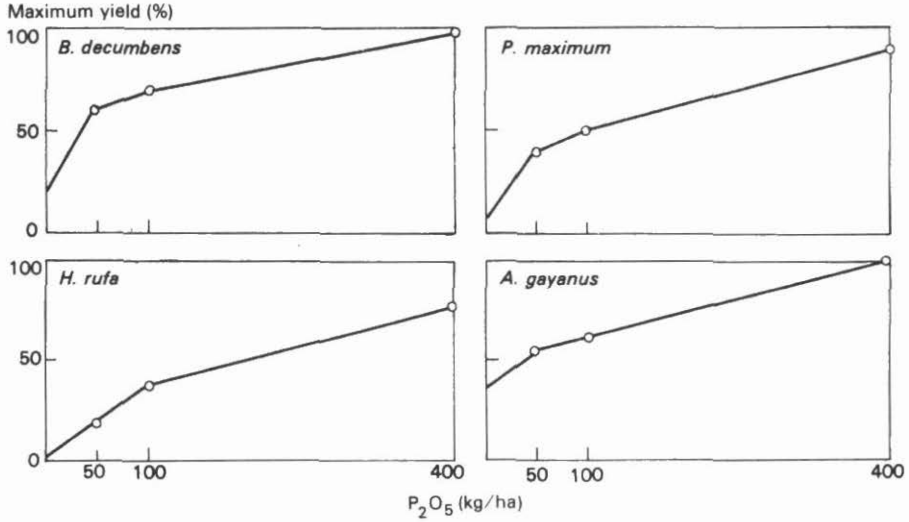

Figure 8. **The relative yield response of four grasses, grown on a Carimagua Oxisol, to varying levels of P. Average of three to four harvests one year after establishment.(Adapted from 3).**

It is imperative that growth response curves with P be run on all of the promising *grass and legume pasture species under a* variety of soil conditions, in order that a higher degree of confidence can be established in making fertilizer P recommendations in tropical Latin America.

USE OF CHEAPER SOURCES OF PHOSPHORUS

The use of PR as a P source for pasture production appears both economically and

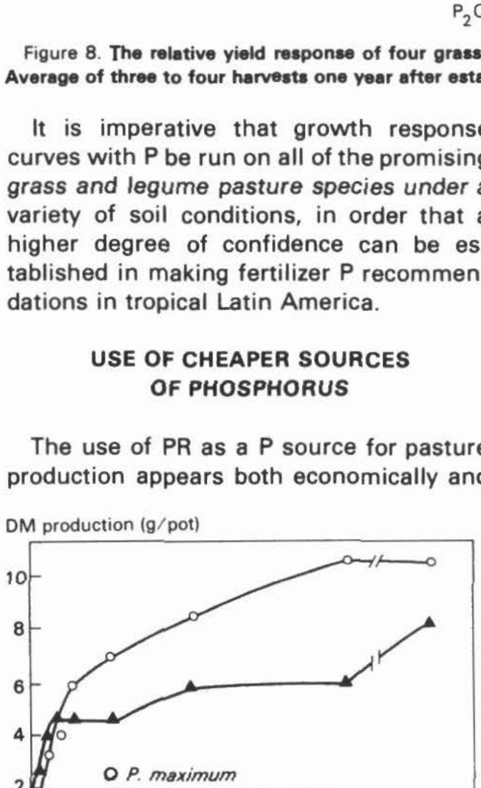

Figure 9. **Effect of varying levels of P on yield of two forage species (two cuttings), grown in a greenhouse on a CIAT-Quilichao Ultisol (3).**

agronomically attractive. Not only is the unit cost of the P much cheaper, one-third to one-*fifth that of TSP or SSP (12), but the residual* value of the product is likely to be greater than the more soluble P carriers. Since the soil P deficient Oxisols and Ultisols of tropical Latin America generally fix large quantities of P (Fig. 7), PR is often more effective than SSP or TSP (4). Also, since PRs are more reactive in acid soils than in *neutral* or calcareous soils it is likely that release of available P is more in unison with the growing forages needs, thus possibly reducing the incidence of P fixation by the soil. Other factors related to the effectiveness of the PRs would be their solubility and fineness of particle size.

The reactivity or relative agronomic effectiveness (RAE) of the PRs in Latin America (Fig. 10) are generally low to medium (5). With time, however, these PRs appear to be an effective source of P in forage production (3, 7, 8, 9).

A number of forage production experiments have been conducted in tropical Latin America using the direct application of PR. Recent works in Brazil and Peru by North Carolina State University (7, 8, 9) and in Colombia by the International Fertilizer

Figure 10. Rock phosphate deposits in tropical South America, 1977.

Development Center (IFDC) and CIAT (3, 5) have shown very encouraging results.

In the Cerrado of Brazil, North Carolina State University and Cornell (7, 8, 9) initiated a long-term experiment with various P carriers on pasture production to determine the effect of using cheaper sources of P. Initially, the highly soluble Hiperfosfato (Morocco) PR performed about as well as SSP. The low reactive Araxá PR from Brazil was ineffective at first, however, after two cuts the availability was increased significantly and yields were comparable to other P carriers (Fig. 11). Rates of P used were 86, 345 and 1380 kg P_2O_5/ha. In the Amazon Jungle of Peru, North Carolina State University (7, 8, 9), in another series of pasture experiments, also showed that Hiperfosfato, Florida, North Carolina, and Fosbayovar (Peru) PRs were comparable to SSP in forage production with *P. maximum.* These two experiments are being continued to further assess the residual values of the P carriers.

In a long-term field experiment at Carimagua, using *B. decumbens* and comparing six PR sources with TSP at P rates of from 0 to 400 kg P_2O_5/ha, Hammond and León (3) conclude that TSP was only superior to PR sources of P at the first harvest. Thereafter, all PRs increased their effectiveness with time and in most instances surpassed the yields of the TSP treatments by the third harvest. After five cuttings, taken over an 18-month period, it would appear that 50 to 100 kg P_2O_5/ha are adequate for near maximum production of *B. decumbens,* regardless of the P carrier used (Fig. 12).

From the previously described experiments, it is apparent that the medium and low reactivity PRs, although they perform well with time, are initially inferior to the more soluble P carriers. The works by McLean and Wheeler (6) would indicate that partially acidulating these PRs to levels of 10 to 20% could overcome this problem. The partially acidulated PR would provide a soluble source of P initially while still maintaining the desirable characteristics of low cost and residual value of the PR. The soluble P in the partially acidulated PR might stimulate the plants initially so they can make more efficient use of the unreacted PR

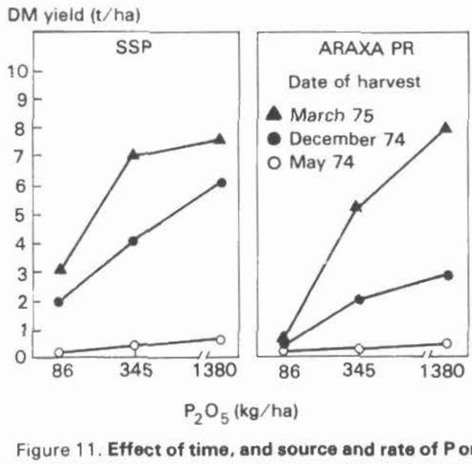

Figure 11. **Effect of time, and source and rate of P on yield of *B. decumbens* grown on a Cerrado Oxisol. (Adapted from 8).**

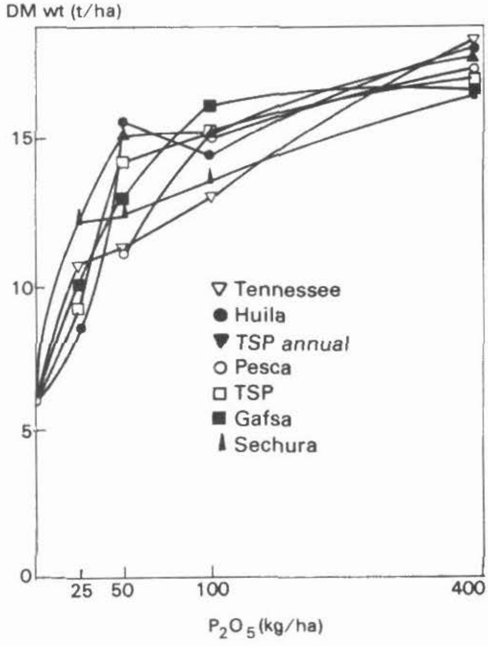

Figure 12. **Effect of P carrier and rate on yield of *B. decumbens* (five cuttings) grown on Carimagua Oxisol. (Adapted from 3 and unpublished data).**

when the soluble P is exhausted. Furthermore, since the P in the unreacted PR is probably becoming available over a period of time, thus providing a continuous supply to the plants, perhaps the adverse common ion effect of the Fe and Al will be somewhat overcome. Although no work has been published in tropical Latin America on the use of partially acidulated PR in pasture production, some research with beans (1) has shown very encouraging results.

USE OF SOIL AMENDMENTS TO ENHANCE THE AVAILABILITY OF APPLIED PHOSPHORUS

One of the main problems encountered with the acid, P deficient Oxisols and Ultisols of tropical Latin America is their fixation capacity (Fig. 7). In order to decrease this fixation capacity, soil amendments such as lime or Ca silicates are sometimes applied to neutralize the exchangeable Al. It is important here to note that the concept of adding lime to make the native P in the soil more available 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, it is unlikely that adding lime would appreciably increase its availability. The concept of adding lime to increase or maintain the availability of applied P, however, has merit.

North Carolina State University conducted a lime-P pasture experiment with *P. maximum* in the Amazon Jungle of Peru (7, 8, 9). In this experiment lime levels varied from 0 to 3.5 t/ha and P, as SSP, from 0 to 200 kg P/ha. The researchers conclude that, "there was a strong response to superphosphate, a lesser one to lime applications, and an interaction between the two. Without lime, an annual application of 50 kg P/ha seems to be the optimum, with a total DM production of 20 t/ha/yr. When lime was applied in the absence of superphosphate, DM production increased to 19 t/ha/yr. When lime was applied at either 2 or 3.5 t/ha and superphosphate at 25 kg P/ha, maximum DM production of 25 t/ha/yr was reached" (Fig. 13). The researchers further indicated

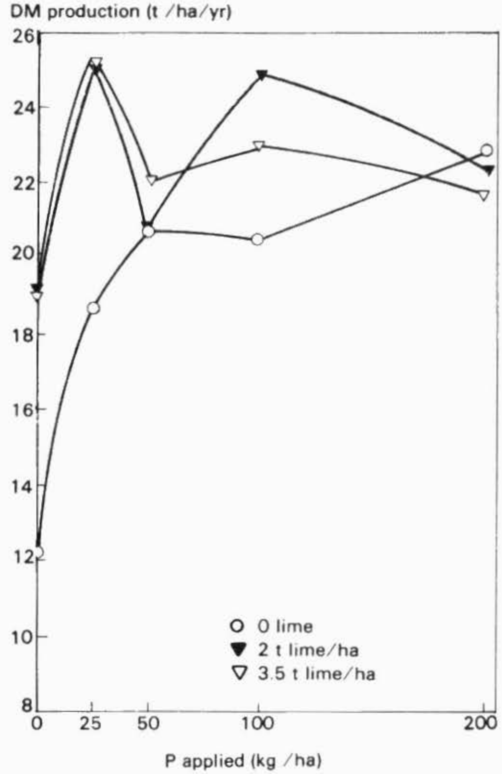

Figure 13. **Effect of P (SSP) and lime on yield of *P. maximum* (six cuttings) grown on a Yurimaguas Ultisol. (Adapted from 8).**

that although the Al saturation was fairly high (64%), only 4 t/ha of $Ca(OH)_2$ was needed to completely neutralize the exchangeable Al. This was because of the sandy texture of the surface horizon of this soil. Nevertheless, this experiment is very important as these sandy textured Ultisols cover large areas of the Amazon Jungle, and other parts of Latin America.

In another pasture experiment, conducted by North Carolina State University (7) at the Cerrado Center in Brazil, varying lime and P rates were applied using *B. decumbens* and *Stylosanthes humilis* H.B.K. as test crops. After two cuttings the *B. decumbens* appeared to respond to the 4.5 t lime/ha at P rates of 86 and 345 kg P_2O_5/ha (Fig. 14). The yield increase from the lime was about 1

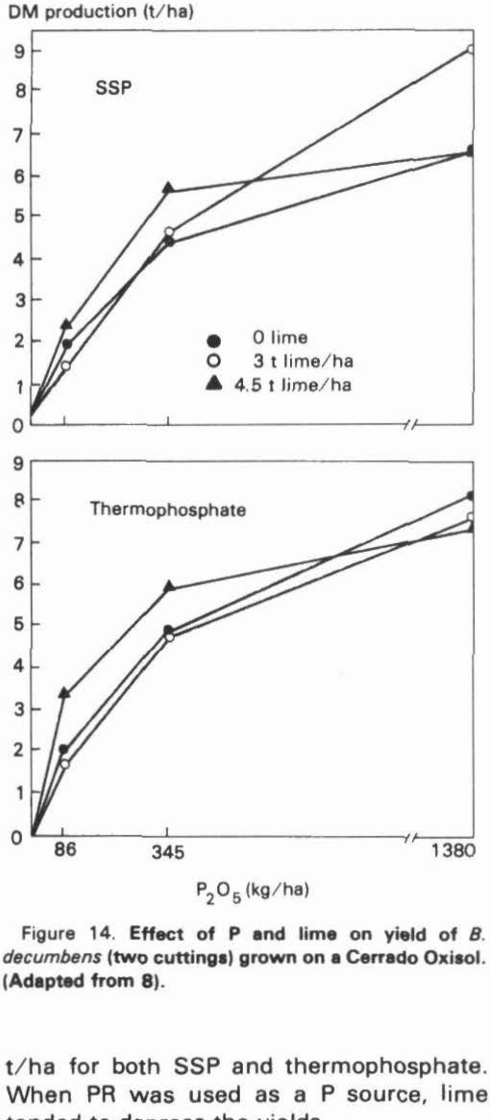

Figure 14. **Effect of P and lime on yield of** *B. decumbens* **(two cuttings) grown on a Cerrado Oxisol. (Adapted from 8).**

t/ha for both SSP and thermophosphate. When PR was used as a P source, lime tended to depress the yields.

With *S. humilis* the researchers obtained significant yield responses to lime (Fig. 15). They state, "this is of interest since other workers have shown that this and other *Stylosanthes* species favor only moderate Ca levels. This response was particularly apparent at the rate of 345 kg P_2O_5/ha with ordinary superphosphate and thermophosphate, where yields more than tripled with increasing rates of 0, 1.5 and 4.5 t lime/ha".

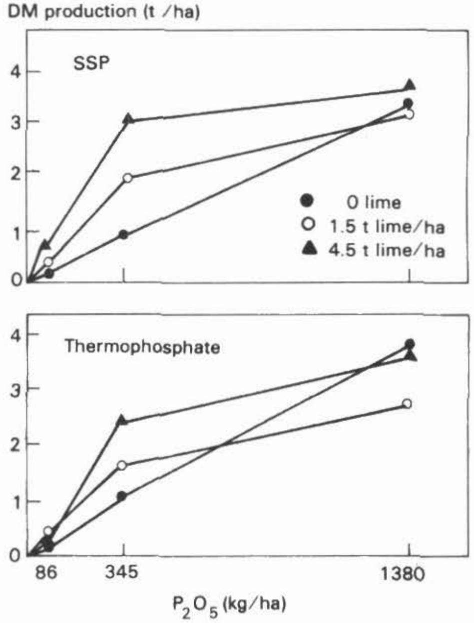

Figure 15. **Effects of P and lime on yield of** *S. humillis* **(one cutting) grown on a Cerrado Osixol. (Adapted from 8).**

León (3) conducted a greenhouse experiment, using a Carimagua Oxisol, in which varying rates of P were applied with combinations of Ca silicate, lime and Mg oxide. In all cases the addition of one or more of the amendments significantly increased the yield of *Stylosanthes guianensis* (Aubl.) Sw. (two cuttings) over that of TSP applied alone (Fig. 16). 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 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 Smith (13) in Brazil would indicate, however, that there is definitely an amendment effect of neutralizing the exchangeable Al from both the lime and Ca silicate (Table 2).

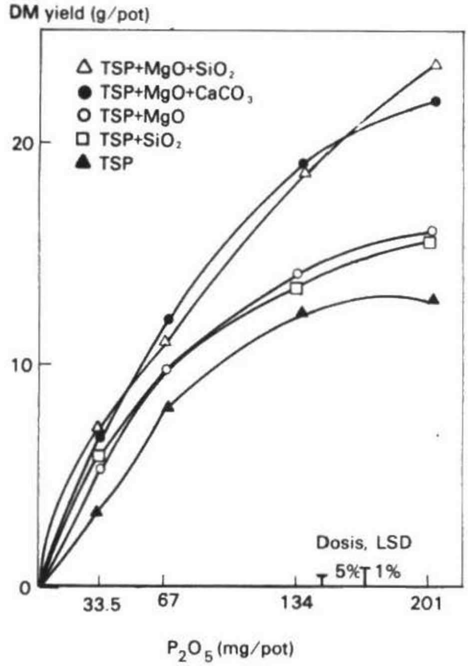

Figure 16. **Effect of TSP, alone and in combination with soils amendments, on yield of *S. guianensis* 136 (two cuttings) grown in the greenhouse on a Carimagua Oxisol. (Adapted from 3).**

CONCLUSIONS

Although there has been a considerable amount of research done on improving pasture production on the acid, P deficient soils of tropical Latin America, it is clear that many problems must still be solved from a P management standpoint. Selecting forage species that utilize limited amounts of P most efficiently must be given top priority. This is very important since most of the soils are not only P deficient but also tend to fix appreciable amounts of fertilizer applied P.

Based on the previously discussed experimental results, it would appear that even the low P requiring plants need substantial amounts of fertilizer P. It is therefore important that cheaper forms of P carriers be used to accommodate these needs. Since PR is the cheapest form of P available it is important that long-term, comparative studies be conducted with the various rocks and their low-cost altered products to ascertain if it is feasible to use them in deference to the more soluble, costly P carriers. Further research is also needed to determine the effect of added amendments on the availability of applied P.

When these problems have been further researched, it should then be possible to make relatively accurate P fertilizer recommendations for any given pasture management scheme. This will only be accomplished when both the plant and soil P needs are better understood and related to the animal's own nutritional requirements.

Table 2. **Decrease in P fixation by lime and silicate applications sufficient to neutralize exchangeable Al in a clayey Oxisol from the Cerrado of Brazil with an original pH of 4.6, 1.45 meq Al/100 g and 80% Al saturation. (Adapted by Sánchez (12) from Smith (13)).**

Amendment applied	P fixed to give			Decrease in P fixed		
	0.03	0.10	0.20	0.03	0.10	0.20
	ppm P in solution			ppm P in solution		
	ppm			%		
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

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