INCREASING THE EFFICIENCY OF UTILIZATION OF SOIL AND FERTILIZER PHOSPHORUS IN THE SUBTROPICAL AND TROPICAL AGRICULTURAL SYSTEMS C*

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RESUMO

A falta de P no solo é o fator que com mais freqüência limita a produção nas condições brasileiras, particularmente a das culturas anuais. A eficiência da adubação fosfatada pode ser aumentada de diversas maneiras que às vezes são empregadas conjuntamente, a saber: 1) Calagem - aumenta o fornecimento de P do solo e diminui a conversão do P do adubo em formas de menor aproveitamento; 2)

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Localização diminuindo a proporção do fósforo fixado aumenta a absorção; 3) Tipo de adubo - o aproveitamento do P_2O_5 pode variar em função do adubo usado; 4) Espécies e variedades - o aproveitamento do fósforo na formação da colheita é influenciado pela capacidade da planta; 5) Análise do solo - as quantidades de adubo a usar são função do teor de P do solo e da relação entre custo do fertilizante e valor do produto agrícola; 6) Magnésio - a absorção do P do adubo depende do teor de Mg no solo podendo por isso ser aumentada pelo fornecimento de calcário dolomítico ou de sais solúveis de magnésio.

INTRODUCTION

The low P level, very often associated with high acidity, is the factor which more frequently limits agricultural production in the tropical regions, and to a lesser extent, in the subtropical conditions as well (ROCHE **et al.**, 1980).

The two major soil types, namely oxisols and ultisols, are highly weathered and leached, acidic, presenting a high sexquioxide content.

According to SANCHEZ & SALINAS (1981) phosphorus deficiency is to be found in 82% of the area of tropical America; the area covered by acid soils is even larger reaching 96% of the total. These figures agree quite well with earlier estimates made by MALAVOLTA (1976, p. 527) showing thet nearly 90% of the soil samples analysed in Brazil could be classified as low in available P. From the stand point of fertility the results showing in table 1-1 could be considered as typical of the savanna or cerrado ecosystems which are present both in Latin America and in Africa: on the average available phosphorus content is exceedingly low, < 1 ppm, which corresponds to only 3 kg per hectare, not sufficient for the growth of any crops. This explains why, under these conditions, P fertilization represents the difference between having or not having a harvest.

On the other hand, the demand for P is further enhanced by the high fixation power of such soils which is a consequence of low pH and of the high sexquioxide content, two prevailing features already pointed out. BOYER (1982, pp. 181-2) collected information with respect to the phosphorus fixing capacity of the ferralitic soils representative of tropical and subtropical regions, as shown in table 1-2.

Data on the fraccionation of soil P are coherent with those related to fixation since aluminum and iron phosphates (P-Al and P-Fe, respectively) represent the dominant forms, in excess of calcium (Ca-P) phosphates of hogher solubility in the soil system (see table 1-3 prepared with data od BOYER, 1982, pp. 117-120). Another indication is derived fron these figures: the ratio available P/total P is usually much lower than 1/40.

Tropical and subtropical regions which allow for rainfed agriculture do not possess large deposits of soft, high reactivity rock phosphates: proven Brazilian reserves, for instance, will be depleted in circa 50 years of use. And since there is no possible replacement for phosphorus in the life of plants, the limits of growth of these regions is set by the size of its P deposits - or by its capacity of importing and processing phosphatic rock from elsewhere.

Table 1-1 Main chemical characteristics of Brazilian cerrado (Savanna) soils (*)

Characteristic	Average value
pH	5.00
Organic matter (%)	2.20
Exchangeable (meg/100 ml)	
K^+	0.08
Ca^{+2}	0.25
Mg^{+2}	0.09
Al^{+3}	0.56
CEC	1.10
Al saturation	59
P ppm	0.40
Cu	0.60
Fe	33
Mn	8
Zn	0.60

(*) adapted from LOPES (1977).

P, Cu, Fe, Mn, and Zn: in 0.05 HCl + 0.025 N H_2SO_4

Table I-2. P fixing power of selected subtropical and tropical soils.

Country or region	P fixed ppm
Nigeria	20 - 40
Togo, Dahomey, Guinée	30 - 370
Cote d'Ivoire	30 - 800
Puerto Rico	375 - 1100
Brazil	500 - 700

The need for efficient utilization of both soil and fertilizer phosphorus is therefore a matter of great concern.

LIMING

The relationship between pH and prevailing form of P is well known: in the range of pH 3.0 to pH 5.5 P-Fe abound; the P-Al content shows a peak at pH 5.5; the presence of P-Ca in significant proportions is determined when the pH increses from 6.0 to 8.0. The availability Therefore usually is greater in the range of pH 5.5 to 7.0-8.0; values above these are non phsysiological for the vast majority of subtropical and tropical crops. Since the soils under consideration herein are acidic and rich in Fe and Al hydroxides it is not surprising that the highest correlation coefficient between a given characteristic and fixing power is found with respect to iron compounds: FASSBENDER (1975, p. 290) has calculated the regression equation

$$Y = 17.63 + 10.83\ x + 0.890\ x^2 \quad r = 0.432^{*}\ x$$

where y = fixing power, x= % Fe_2O_3.

It follows that a beneficial effect of liming on the utilization of both soil and fertilizer P is to be expected. The literature showing this to be true is rather voluminous.

Fig. 2-1 shows results obtained by ELTZ **et al.** (1975) and by FERRARI **et al.** (1976), being very clear that liming the soil increased the efficiency of utilization of fertilizer P. Earlier, however, MC CLUNG **et al.** (1961) verified that limestone applications actually decreased the size of cotton response to P_2O_5 fertilization. These apparently conflicting results explained, at least in part, by Fig. 2-2: in the soil second case liming the soil released enough of the native P to meet the requirements of the cotton (MALAVOLTA **et al.**, 1955). The beneficial effect of raising pH through liming is sometimes observed even when rock phosphate is the source of P_2O_5. LIMA & MALAVOLTA (1982) suggest that this effect is indirect due to better root invironment created by the limestone which helps the plant to absorb more phosphorus, thereby counter acting the influence of both high pH and high Ca^{+2} concentration on the solubility of the fertilizer.

Summing up, it could be stated that a better utilization of P promoted by liming could be due to several reasons which do not exclude each other:

1. diminution in P fixation;
2. increased utilization of soil-P - "waking" up the "dormant" phosphorus (LARSEN, 1973);
3. improved of the root development by the calcium ion

Table 1-3. Forms of P in tropical and subtropical soils

Country or region	ppm P-sol	 P-Ca	 P-Al	 P-Fe	 P-org.	 P-tot.
Brazil	0-8	244	0-87	4-217	70-1748	122-3306
Nigeria	0-13	6-165	2-74	13-75	130-420	189-938
Guinée						
Dahomey, Cameroun						
Rep. Centraficaine	-	5-74	6-214	1-315	-	-

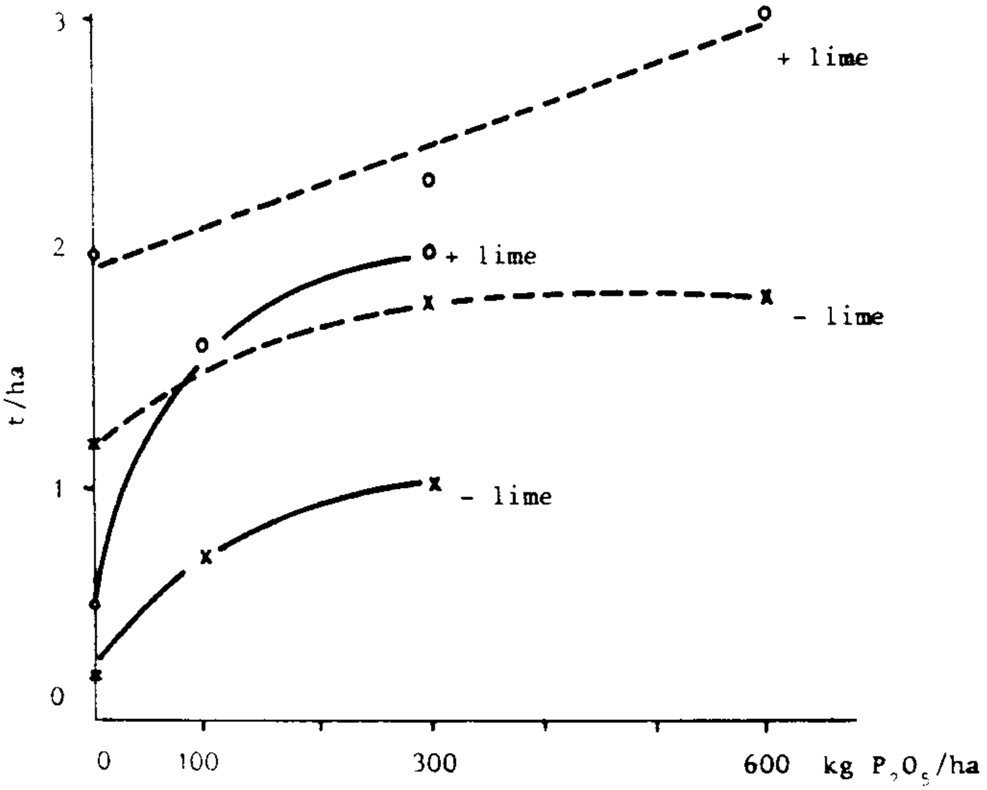

Figure 2-1. Effect of lime and P_2O_5 on soybean in Brazil (solid line: Red yellow latosol, P banded; broken line: Oxisol, P broadcast).

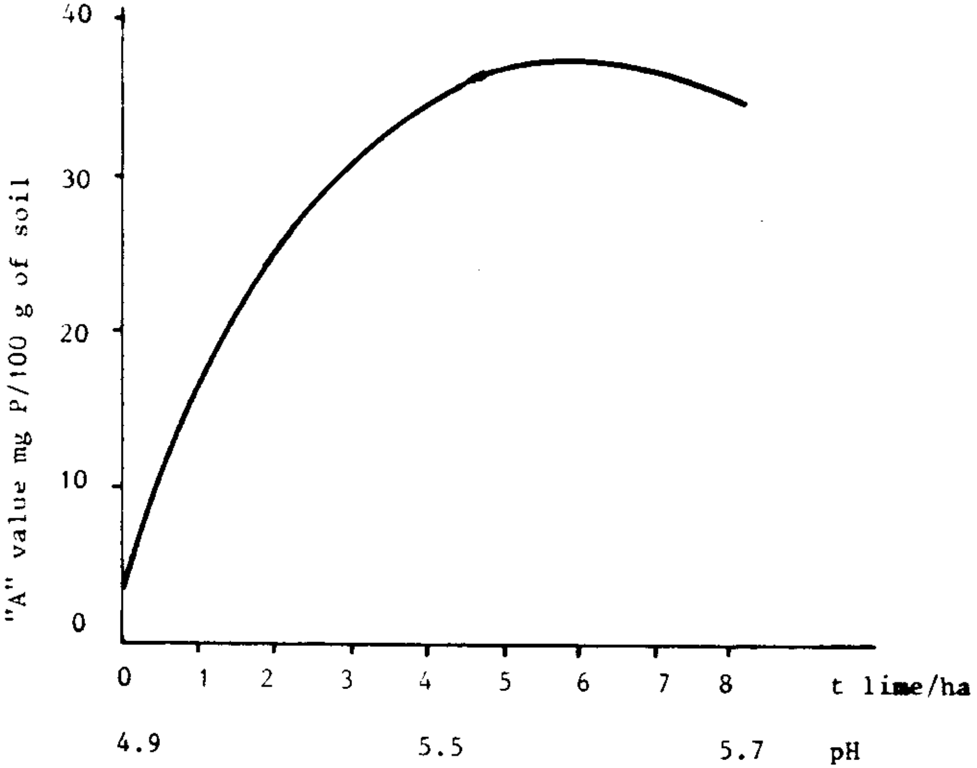

Figure 2-2. Effect of limestone in the "A" value of three cerrado soils.

As pointed out by RITCHEY **et al** (1981, pp. 141-2), high Al saturation restricts root growth; low Ca^{+2} in the soil solution, however, can impose an even more severe restraint. Table 1-1 makes it clear that both conditions occur jointly in the cerrado soils. Phospho-gypsum, either by itself or when applied as ordinary superphosphate, moves down the soil profile which helps roots to develop in deeper layer of soils due to the diminution in Al saturation. As a consequence plants do not wilt as much as those with shallow root system imposed by other phosphatic fertilizer, and therefore, yield more.

PLACEMENT AND GRANULATION

The dynamics of soil and fertilizer P is represented in Fig. 3-1 which is a modification of that drawn by SADLER & STEWART (1974).

An adequate supply of inorganic P, Pi, to the plant (reactions with constants k5 and k7) will be obtained when the level of the element in compartment soln P, (solution Pi) is kept at a heighth compatible to the needs for growth and development. This in turn requires that all reactions whose constants have an even subscript are prevented or kept at a minimum with the possibile exception of those which take place within the plant itself, that is k6 and k8. In practice the chief objective is to reduce fixation or the conversation of Labile Pi into Stable Pi since this represents mostly unavaileble forms.

The contact between Soln Pi and the root system is accomplished chiefly by diffusion which accounts for 92% of the total quantity which can be supplied; the remaining contribution is that of root interception and mass flow, according to the well established data of BAR

BER (1966). It is necessary therefore to place Fertilizer Pi as close as possible to the root system so that a concentration of Soln Pi of the order of 0.3 to 0.5 ppm could be kept during most of the life cycle.

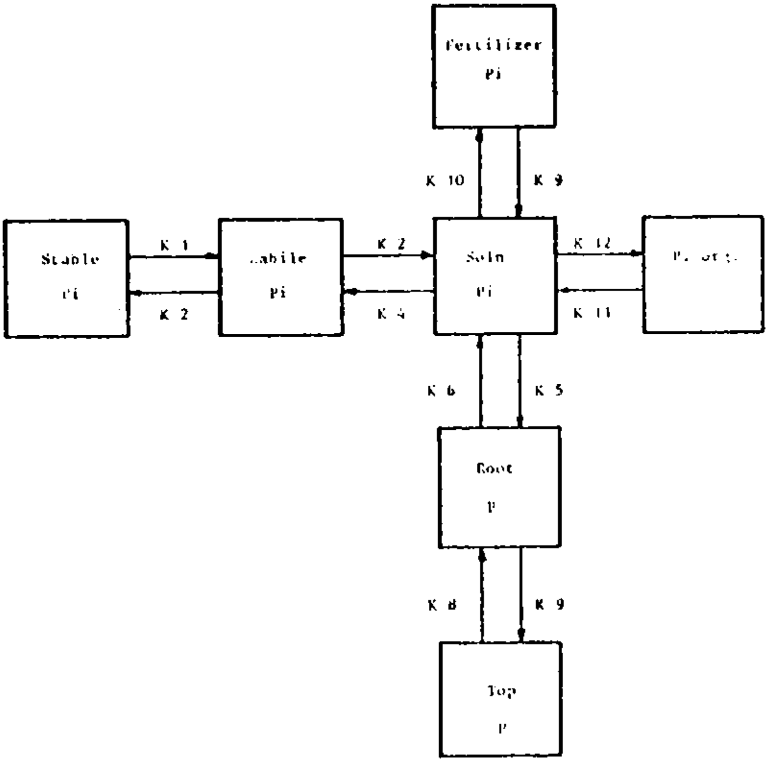

Figure 3-1. Dynamics of soil and fertilizer P (see text).

Broadcast and incorporation of the Fertilizer Pi in the top 20-30 cm layer would apparently maximize supply to the root system since the element would occupy nearly 100% of the soil volume. This, however, would encourage fixation (reactions with constants k4 and k2). The placement of the fertilizer in bands at one or two sides and below the seed is the usual alternative. This practice, on its turn, makes that only 1-2% of the soil volume receives P. There are limitations on the root capacity to absorb phosphorus. Since only a restricted root surface is accessible to the P which diffuses out of the fertilizer granule or particle, then the possibility exists that growth and yield may be limited by lack of P (GACHON, 1977). This led BARBER (1977) to work out a compromise solution: application as a strip to contact about one tenth of the surface followd by mixing and plowghing. When compared with banding by row and broadcast and plowghing, this type of positional placement gave, respectively, 0.5 and 1.0 t/ha of corn more, average of 5 years of experiments.

As a rule in the acid, low in P soils of the subtropical and tropical regions, due to the modest rates of P_2O_5 used, banding gives better results than broadcast applications. This is shown in Fig. 3-2 and 3-3 taken from VEGA **et al**. (no date). One the other hand, when relatively high doses are used, broadcast followed by plowghing in gives higher initial yields, as the results in Table 3-1 (YOST **et al**., 1976) demonstrate. On the long run, however, it seems to be better to band the fertilizer each year than use massive applications once, the reason being, of course, the fact that the half life of Ferilizer Pi decreases with the dosage (Figure 3-4): on the other hand the use of a high dosage could represent too heavy an investiment in terms of expenditure.

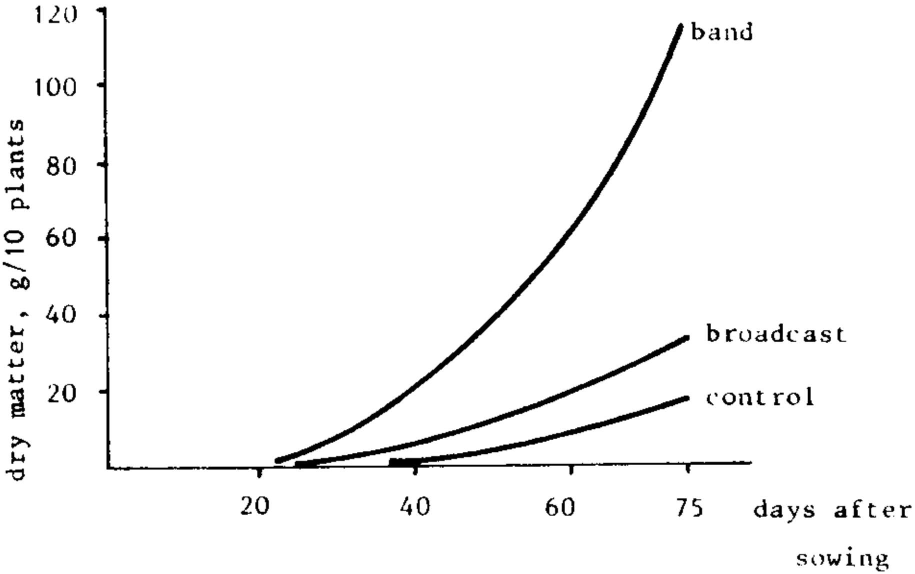

Figure 3-2. Effect of placement on yield.

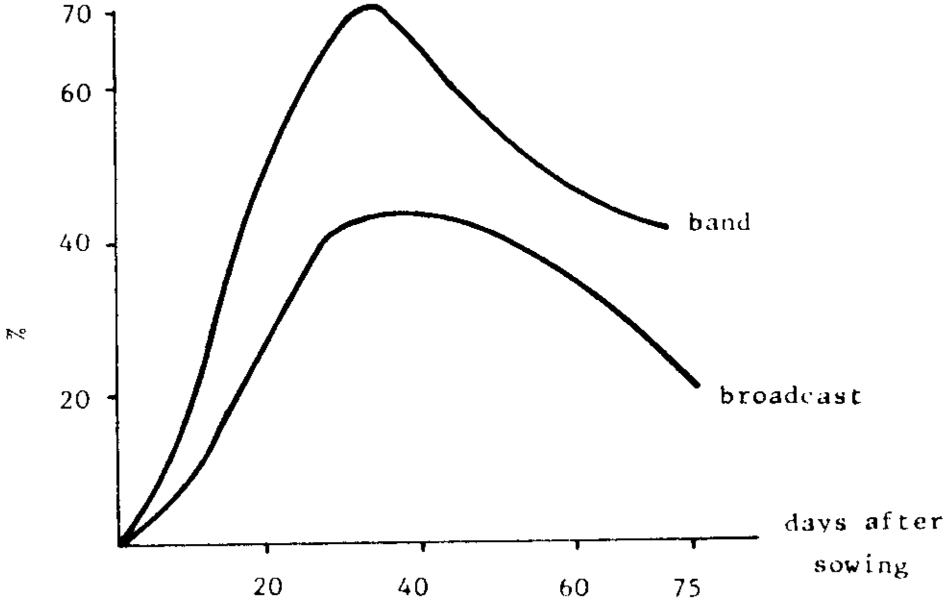

Figure 3-3. P in plant derived from the fertilizer.

Table 3-1. Effect of rates and placement of phosphorus on corn yields in a Brazilian oxisol.

kg P_2O_5/ha Broadcast (*)	Banded (**)	t corn/ha				
		1st crop	2nd	3rd	4th	Sum
160	-	5.23	3.27	0.88	1.79	11.17
320	-	6.28	5.69	2.21	3.43	17.60
640	-	6.80	7.48	2.98	6.44	23.69
1280	-	7.96	8.54	3.88	9.03	29.40
-	80	2.42	5.08	3.08	6.03	16.60
-	160	3.85	6.57	3.41	8.07	21.92
-	320	4.80	8.43	4.19	9.04	26.46
320	80	6.60	7.32	3.33	7.22	24.54
80	80	3.59	6.00	2.56	6.49	19.62

(*) at the begining of the experiment only

(**) each year at planting

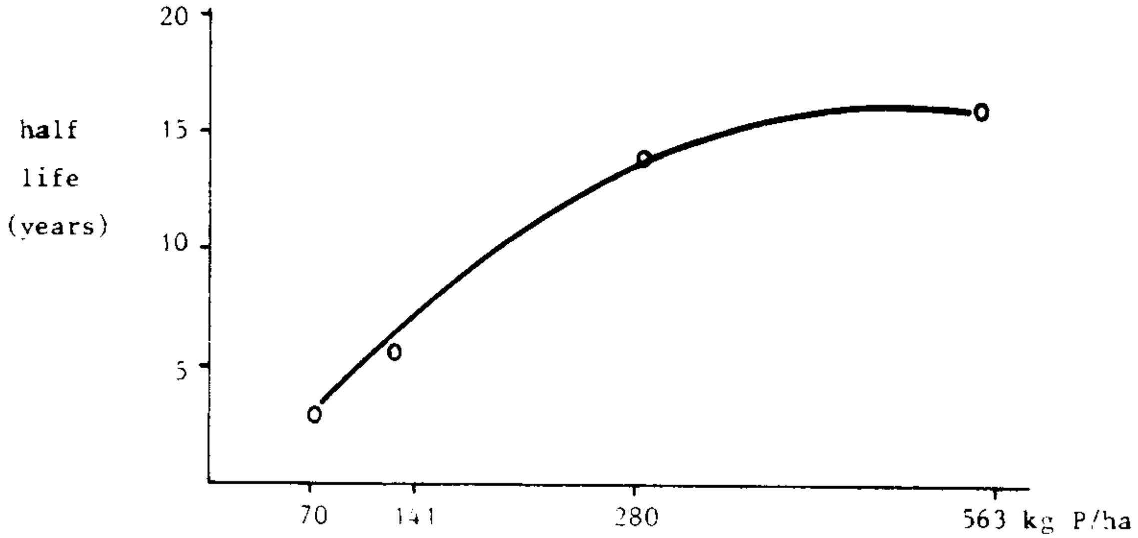

Figure 3-4. Effect of the initial rate of broadcast P on the half life.

In the case of perennials, coffee, a surface application in the dripping line allows for a higher uptake of Fertlizer P than distribution in the bottom of circular furrows as shown in Table 3-2 taken from MALAVOLTA & NEPTUNE (1977); foliar applications, however, are much more efficient.

Table 3-2. Absorption of tagged superphosphate by coffee plants in function of method of application.

Treatment	% of lef P from fertilizer
1st. experiment	
Top dressing (circular strip)	10.2
Circular furrow	2.4
Semi circular furrow	1.7
Leaf spacy spray	38.8
2nd. experiment	
Top of mulch	12.3
Under mulch	12.5

In soils with higher Labile Pi and less fixation power the effect of broadcast applications can be increased simply by broadcast in the fertilizer before plowghing the land, rather than spreading it and then plowghing; the first alternative causes an enriched zone to be formed in deeper layers of the soil profile which helps the established crop to stand better dry spells which may occur along the growing season. It is self evident that deep placement of the fertilizer band would have similar effect when this method of application has to be used (ANONYMOUS, 1980).

Granulation can prevent, to some extent, the fixation of Fertilizer P provided it is soluble. The effect on rock phosphate would, however, be the opposite since its availability depends upon solubilization in the soil which is helped by the increase in the surface of exposition. Fig. 3-5 prepared from data of BARRETO **et. al.** (1978) gives support to this statement.

MICROORGANISMS

Microorganisms play at least there roles concerning utilization of soil and Fertilizer P.

As shown in Fig. 3-1, the reaction with constant kll consists in the mineralisation of P org. This source of phosphorus may be a very important one as in the case of some Brazilian and West African soils in which cocoa is grown. The following figures are representative: P org. = 1,300 kg/ha, Stable Pi = 900 kg/ha, Labile Pi + Soln = 10 kg/ha.

It is well established, that many soil microorganisms, on the other hand, help to drive reaction Stable Pi → Labile Pi This is due in part to the fact that such organisms (*Penicillium*, *Aspergillus*, *Rhizopus*, *Candida*, *Oidiodendron*, *Pseudogymnoascus*, *Pseudomonas*) abound in the vicinity of plant roots. Soil microflora produces both organic acids and chelating agents such as 2-ketogluconic acid which render both P and Ca soluble

(KATZNELSON **et al.**, 1962; FERNANDES, 1960-a, b). Seed inoculation with P solubilizing microorganisms (*Bacillus megatherium* var. *phosphaticum*) increased significantly the utilization of added phosphatic fertilizers (superphosphate and hydroxy apatite) by oat seedlings (BAJPAI, 1968).

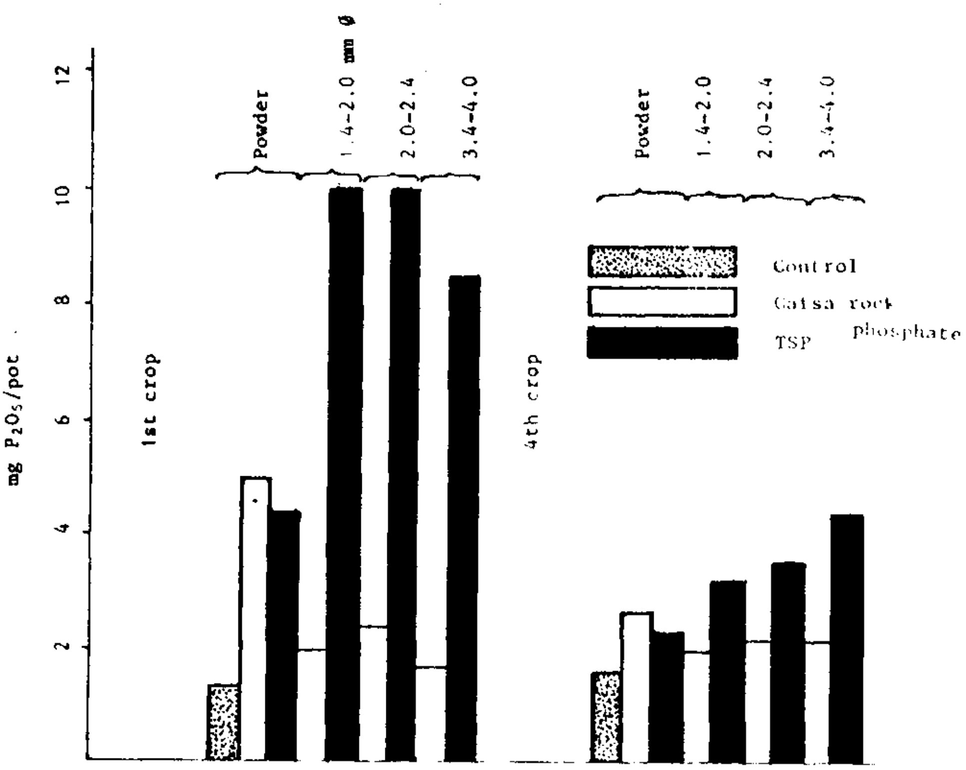

Figure 3-5. Effect of granulation on P uptake by wheat in a Latosol (after BARRETO **et alii**, 1977)

Soln P uptake is increased by mycrorrhizal fungi due primarily to the fact the hyphae expand root surface. Besides this direct effect, another on has to be considered. Since P soln is depleted faster, transfer of Labile Pi to the soil solution, and perhaps, conversion of Stable Pi into Labile Pi is enhanced; in other words: solubilization and diffusion are increased. For details on the role of rhizosphere microorganisms (not only mycorrhizal) see TINKER (1980, pp. 617-654) and LOPES & SIQUEIRA (1981, pp. 225-242).

It should be kept in mind, however, that mycorrhizae usually help only in situations wherein the actual transfer of Labile Pi to the root via Soln Pi is the rate limiting step in the overall system depicted in Fig. 3-1. This is, of course, the case found in soils where available phosphorus is low.

Since this presents a condition for an effect of the myzorrhizal association to be relevant, it becomes clear that: (1) little influence, if any, is to be expected whenever the soil has an ample supply of available P; (2) high yields are hardly to be ontained without the use of Fertilizer Pi.

The effects of mycorrhizae, either native or inoculated, are commonly dramatic in pot experiment. Under field conditions, however, the benefit therefore may be negligible as shown in Fig. 4-1 prepared with data presented by ANONYMOUS (1981). This does not mean however, that the role played by micorrhizae within a natural or man modified ecosystem could be ignored; although not overemphasized, it could be significant whenever natural, active populations do not exist or do not thrive for lack of a favourable environmet.

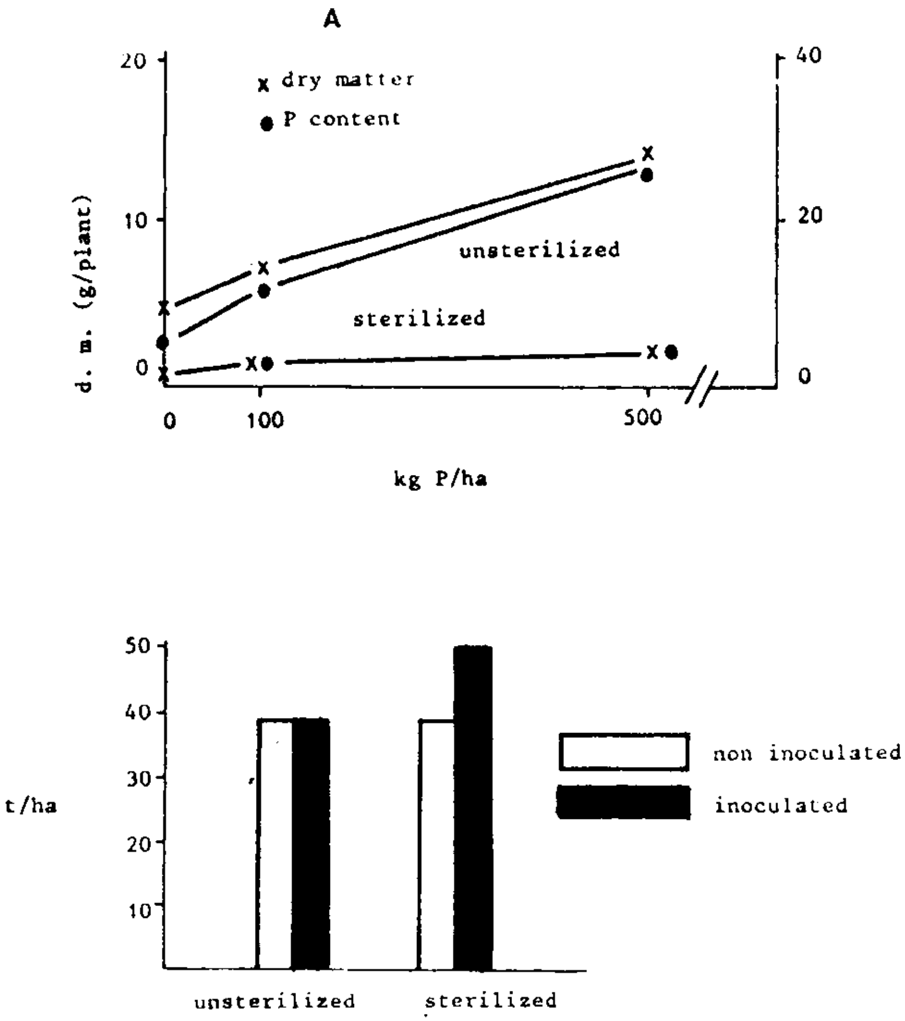

Figure 4-1. Effect of mycrorrizae in cassaca:
A. pot experiments, 2 month duration
B. field trial, 11 month duration.

GENETICAL ASPECTS

Uptake, long distance transport, redistribution and utilization of nutrients for yield formation represent processes which are under genetical control (EPSTEIN, 1975, pp. 269-285).

On the whole P efficient species or varieties should posses a high capability of converting the element in the final product, as defined by the simple equation

$$E_p = \text{yield. P absorbed}^{-1} . \text{cycle}^{-1};$$

in other words, high E_p varieties should be able to produce more with less P taken up, transported and assimilated.

It is not sufficient therefore that a given species or cultivar is merely able to absorb more phosphorus per unit of root length or root weight due to a lower km. In this context differences among species or cultivars are known to exist, as shown in Fig. 5-1 and in Table 5-1. The reason for the statement being the fact, that, other external factors remaining constant, the velocity of transfer of P soln to P root may very according to the size of root system, root morphology and distribution in the soil volume (BARBER, 1982).

What really matters, then, is the plant ability of transforming P taken up, transported or redistributed in to teh product which is the goal at harvest: çeaf, stalk, tuber or root, fruit or grain. It is not enough that positive relationships are found with total dry matter when most of the matter produced is of little or no value for comsuption or sale.

There are striking differences among cultivars in this respect. A few examples are given:

1) Table 5-2 shows the amounts of P wich Brazilian

upland varieties of rice, allow yielding utilize for the production of 1 t of rice in comparison with IR 8, high yielding variety;

2) Fig. 5-2 indicates that low yielding varieties export relatively less P than IR 8;

3) Table 5-2 presents the E_p values for the cultivars under consideration.

For details see MALAVOLTA & FORNASIERI (1983, pp. 15-62).

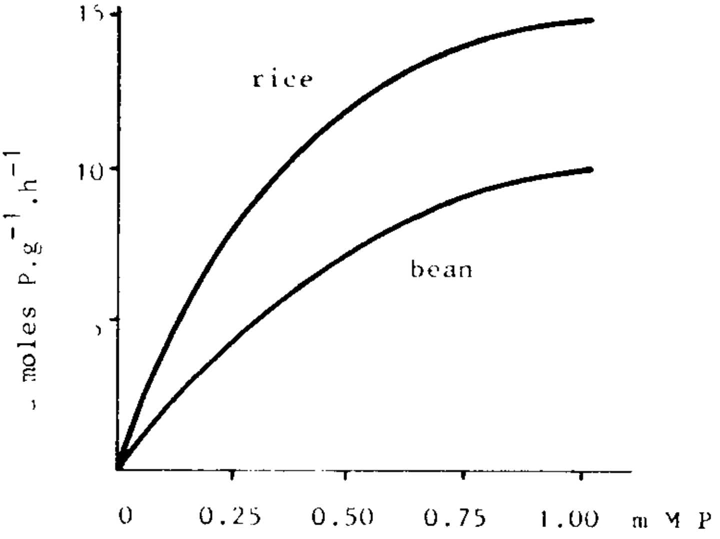

Figure 5-1. Uptake of P by excised roots of rice and bean.

Table 5-1. Genotypes differences on P uptake by excised corn roots.

Variety or hybrid	μ moles P. g^{-1} .h^{-1}
AG 504	5.5
AG 152	3.5
Piranão	3.2
H 7974	2.2
Flint composto	2.0
Centralmex	1.7

Table 5-2. Phosphorus absorbed for the production of 1 t of rice grain and E_p values.

Variety	Kg P	E_p
IAC-47	10-15	0.83
IAC-164	10	0.86
IAC-165	10	0.81
IR-8	5	1.58

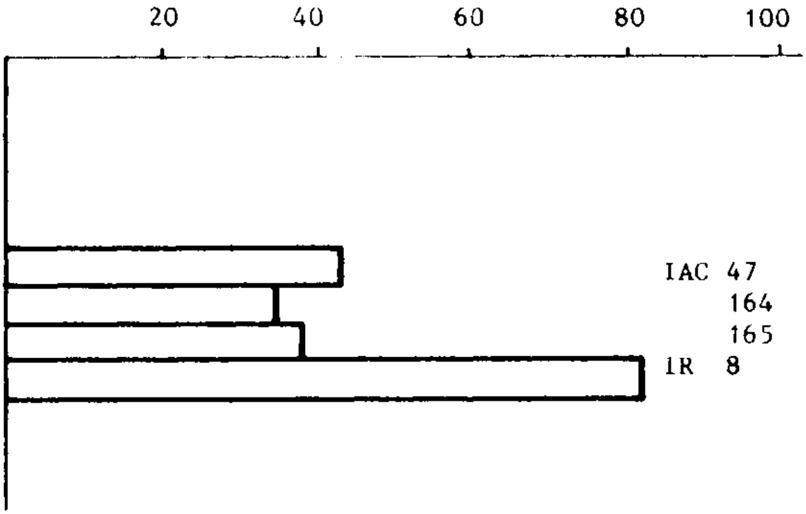

Figure 5-2. P exported as % of P absorbed by rice varieties.

On the other hand, within upland rice cultivars, differences do exist in their responsiveness to P fertilization as shown in Fig. 5-3, redrawn from FAGERIA & BARBOSA Fº (1981). In this particular case it remains to be seen whether the fact that some varieties yield more than others at relatively low levels of soil P is due to more efficient absorption or utilization, or due to the possibility of their roots being able to release the element from otherwise unavailable forms (JAYMAN & SILVASUBRAMANIAN, 1975). Other explanations are, of course, possible to exist.

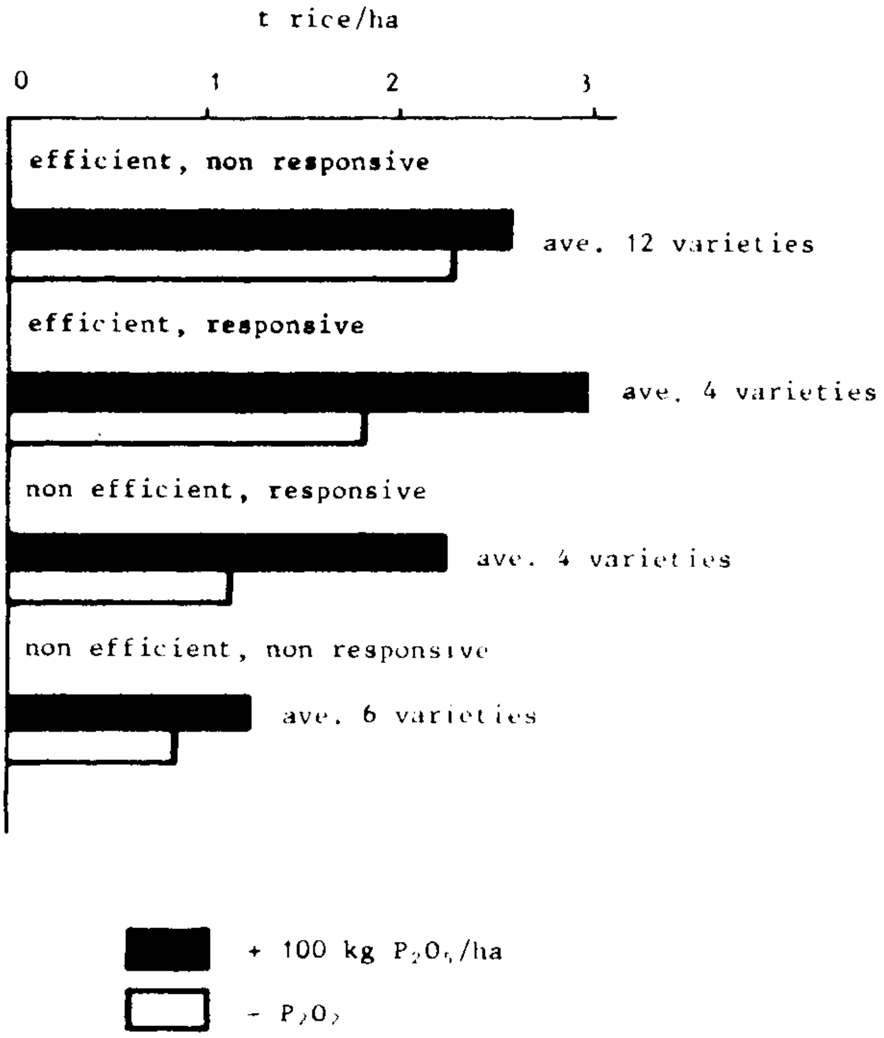

Figure 5-3. Utilization of soil and fertilizer P by rice varieties.

Efficient P utilization is a characteristic sometimes associated with tolerance to excess Al in the substrate as Fig. 5-4 indicates (MALAVOLTA **et al.**, 1981): the benefit derived would, therefore be double--lower needs of P_2O_5 fertilization and less lime to correct soil acidity.

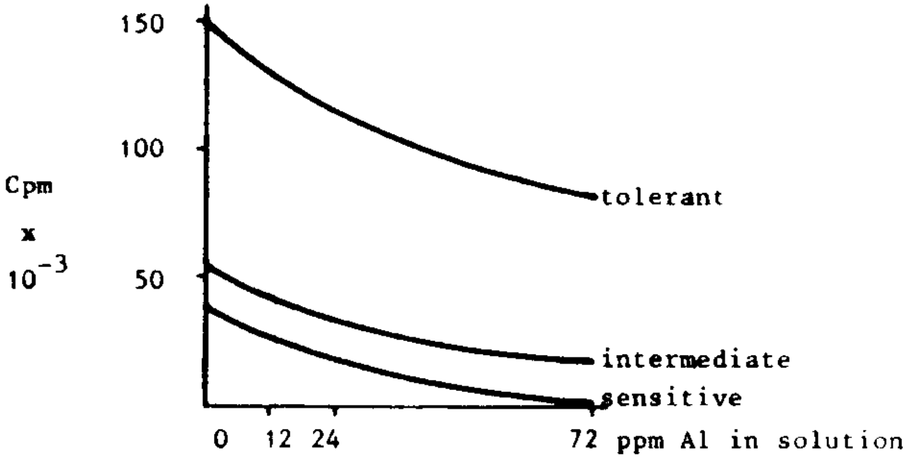

Figure 5-4. Influence of Al on P uptake and transport in sorghum (simplified) (ave. of 8 hybrids).

SOURCES AND RATES

A large number of experiments carried out in subtropical and tropical regions show that citric acid and citrate soluble sources of P_2O_5 are, as a rule, as efficient as the water soluble products. This could be explained to a large extent by the chief soil characteristics - high acidity and high P fixing power.

Table 6-1 gives the results of an experiment with sugar cane (ALVAREZ **et al.**, 1965) showing that magnesium thermophosphate (Mg TP) gave higher yields than ordinary superphosphate (OSP) a finding which is confirmed by other trials with different species. Altough the unit cost of P_2O_5 in Mg TP is higher than in OSP, the two sources have the same relative economic efficiency (Table 6-2). This type of results is due to several reasons besides the soil characteristics, one of them being the Mg content. As demonstrated by LOURENÇO **et al.** (1968) magnesium ions stimulate P uptake (Fig. 6-1) apparently by lowering kms in the two isotherms which describe the kinetics of absorption (Table 6-3). Working with soil MADRID **et al.** (1977) verified that magnesium sulfate increased the fertilizing value of triple superphosphate, dicalcium phosphate and octacalcium phosphate; in all cases the effect was due to higher uptake of Fertilizer Pi.

Table 6-1. Effect of ordinary superphosphate (OSP) and magnesium thermophosphate (Mg TP) on sugar cane yield (t/ha).

kg P_2O_5/ha	OSP	Mg TP
0	63	63
50	80	88
100	88	97

Table 6-2. Economics of OSP and Mg TP use.

Item	OSP	Mg TP
Response curve	$y = 95\,(1-10^{-0.0066x})$	$y = 116\,(1-10^{-0.0054x})$
Maximum economical rate of P_2O_5 (kg) (x^*)	142	175
Max econ. yield (t/ha) (y_e)	84	103
Relative econ. yield, OSP x Mg TP (rey)	0,59/0,59 = 1	

$x^* = \frac{1}{2}x_u + \frac{1}{c}\log\frac{wu}{tx_u}$; x_u = rate of P_2O_5 which increases yield in u t of cane; w = unit price of sugar cane (Cr$5,000/t); t = unit price (kg) of P_2O_5 in fertilizer, Cr$ 285, OSP and Cr$ 368 for Mg TP (1 US$ = Cr$ 500)

rey = ye OSP/x* OSP ÷ ye Mg TP/x*Mg TP

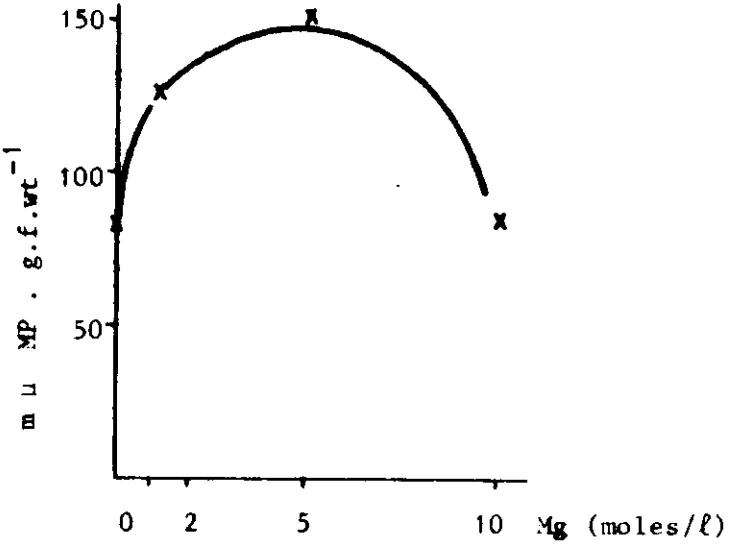

Figure 6-1. Effect of magnesium on P uptake by excised barley roots.

There is a good deal of interest, and a correspondingly large number of publications, on the direct application of rock uptake (RP) (BRAGA, 1970; KHASAWNEH & DOLL, 1978; LEON & FENSTER, 1979; OLIVEIRA **et al.**, 1982). In this respect, however, one could safely say that if all the results of experiments with RP were placed side each one would point to a different direction". Among the avriables which influence the effect compared to that of soluble Fertilizer Pi, the reactivity of the product is the main one. Except in the case of soft RP of secondary origin it does not seem valid to think that these products can compete effectively with acidulated or fused phosphates. They may have a place, however, in the so called corrective fertilization in which high rates are broadcast and ploughed in and no short term results are expected.

Table 6-3. The apparent dissociation constants in phosphste uptake by barley roots under the influence of Mg ions.

Mg moles/l	moles/l Km_a	 Km_b
0.0	1.1×10^{-4}	7.7×10^{-6}
1×10^{-5}	1.2×10^{-4}	3.4×10^{-6}
2×10^{-5}	2.0×10^{-4}	4.5×10^{-6}
5×10^{-5}	1.2×10^{-4}	2.8×10^{-6}
1×10^{-4}	6.7×10^{-4}	1.0×10^{-6}

Partially acidulated roch phosphate (PARF) shows a great promise as cources of P_2O_5 as demonstrated in pot and field experiments with different crops (see Fig. 6-2). There is an obvious - and not so new interest (COOKE, 1956) in this type of product in countries where sulfur as a new material, has to be imported. This "modified OSP" contains S which represents an added agricultural value. Along the same technological line, the partial solubilization of RP *via* ammonium bisulfate deserves consideration.

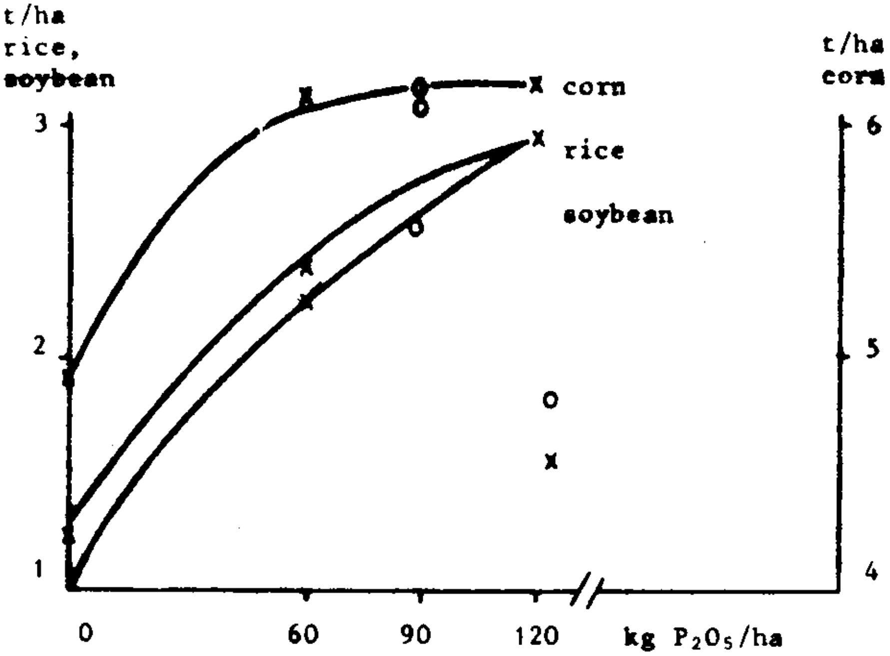

Figure 6-2. Effects of ordinary superphosphate (OSP) and a 50% acidulated rock phosphate (PARP) on several crops.

Recommendations for P fertilization in the case of non perencial crops is usually based on soil chemical analyses. For the extraction of available P (= Labile Pi + Soln Pi + fraction of Stable Pi) many extracting solutions (and more recently exchange resins) are used in an attempt to simulate in the laboratory what roots do in the field. Whatever the extracting procedure employed, it is compulsory that they show a high power of resolution among soils with different levels of available P. In other words: the classes which define the phosphorus status of the soil should be sufficiently narrow to allow for more precise recommendations: otherwise the rates to apply would be either insufficient or excessive. In the first case the yields would not show the desirable increase, and in the second case, the results could be either detrimental or less economical.

Increasing the efficiency of utilization of Fertilizer P is a proposition to be finally examined within the overall economics of fertilization. In Brazil, for instance, fertilizers and their distribution in the field represent from 5 (sugar cane) to 15% (upland rice) of the cost of production; in other countries, wherein most or all fertilizer must be imported, the figures could be even higher. This means that recommendations for P fertilization should take into account the ratio w/t between unit value of the product (w) and unit cost of P_2O_5 (t), being adjusted whenever the cost of the fertilizer or the value of the agricultural product, or both, are changed. An example is given in Table 6-4 (MARINHO & ALBUQUERQUE, 1978) for sugar cane.

Table 6-4. Rates of P_2O_5 for sugar cane.

Soil P ppm	Level	kg P_2O_5/ha for w/t				
		8	1	20	26	32
< 5	very low	120	150	170	180	190
6-9	low	50	80	100	120	140
10-16	medium	10	40	60	80	100
17-34	high	-	10	30	50	70
34	very high	-	-	10	30	40

Last but not least: although lack of available P is the most frequent limiting factor, other nutrients (N, K, S, sometimes micronutrients such as B, Cu, and Zn) are also very often in short supply. It they are not applied in the needed amounts and in the right proportions relative to P_2O_5, the utilization of both soil and fertilizer phosphorus would not reach the desirable degree of efficiency (WAGNER, 1979).

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SUMMARY

As a rule, soils of the subtropical and tropical regions, in which rainfall is not limiting, are acidic, and low in phosphorus, and, to a less extent, in other macro and micronutrients as well, such a sulfur, boron and zinc.

The establishment of a permanent agricultural practice therefore, demands relatively high usage of liming and phosphatic fertilization, to begin with.

Several approaches, not mutually exclusive, could be used in order to increase the efficiency of utilization of soil and fertilizer phosphorus so that, goal of diminishing costs of production is reached.

The use of liming materials bringing up pH to 6.0-6.5 causes the conversion of iron and aluminum phosphates to more available calcium phosphates; on the other hand, by raising calcium saturation in the exchange complex, it improves the development and operation if the root system which allows for a higher utilization of all soil nutrients, including phosphorus, and helps of stand water deficits which may occur.

The role of mycorrhizal fungi should be considered as a way of increasing soil and fertilizer P utilization, as well as the limitations thereof.

Screening of and breeding for varieties with higher efficiency of uptake and utilization of soil and fertilizer phosphorus leads to a reduction in cost of inputs and to higher benefit/cost ratios.

Corrective fertilization using ground rock phosphate helps to saturate the fixation power of the soil thereby reducing, as a consequence, the need for phosphorus in the maintenance fertilization.

Maintenance fertilization, in which soluble phosphatic sources are used, could be improved by several means whose performance has been proved: limimg, granulation, placement, use of magnesium salts.

Last, cost of phosphate fertilization could be further reduced, without impairing yields, through impairing yields, through changes in technology designed to obtain products better adapted to local conditions and to the availability or raw materials and energy sources.

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