PHOSPHORUS NUTRITION AFFECTING UPLAND RICE YIELD IN SOME BRAZILIAN LATOSOLS

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Introduction

Cultivated area of upland rice in Brazil, in accordance with the policy aiming at promoting agriculture, is increasing gradually as the crop can grow on acidic soils with high content of free aluminum in the newly developed lands. Also the domestic demand for rice is increasing in spite of the crop's susceptibility to drought. Upland rice will continue to occupy an important position as a first introductory crop in newly developed arable lands until it is relayed by soybean or other crops unless other new crops replace it. Phosphorus deficiency in these lands, is one of the major limiting factors to crop production even in the Dusky Red Latosols (Latossolo Roxo) originating from basic rock like basalt. Also the importance of phosphorus fertility in highly weathered soils, which has been emphasized (Alban *et al.*, 1964; Bahia Filho and Braga, 1975; Kamprath, 1977; Udo and Ogunwale, 1977) is such that no economic crop production can be carried out without phosphorus fertilization. The present contribution deals with (i) the nutritional factors controlling yields of upland rice grown in fields of Dusky Red Latosols and Dark Red Latosols, (ii) inorganic phosphorus and available phosphorus forms in soil in relation to phosphorus application and rice yield and (iii) change of inorganic phosphorus forms after prolonged application of superphosphate.

Factors influencing upland rice growth at different planting times

Five representative varieties of upland rice in Paraná, Brazil were grown in the clayey Dusky Red Latosols of Londrina (23°21's, 610 m elevation) and in the sandy Dark Red Latosols of Ponta Grossa (25°6's, 870 m). Seeding was performed 4 times from September to December. Upland rice yield varied with the sowing date as shown in Table 1. Upland rice of December sowing was damaged seriously by drought in Londrina. The highest yields were obtained in September and October sowing in both regions.

Among the factors which limited the yield of upland rice, rainfall was the most important compared with other climatological parameters such as integrated temperature, insolation and rainfall, according to multiple regression analysis. Rainfall from 40 days before flowering to flowering and to a lesser extent from flowering to 20 days after flowering affected grain yield remarkably in both regions. Among the yield components, as shown by the multiple regression analysis illustrated in Table 2, 1000 grain weight was reduced in Londrina (Dusky Red Latosols) whereas the percentage of filled grains as well as 1000 grain weight and to a lesser extent the number of grains per panicle decreased in Ponta Grossa (Dark Red Latosols).

As for the nutrition of upland rice during the growth period, Table 3 shows the range of total uptake and apparent percentage of utilization of nitrogen, phosphorus and potassium at harvesting time in both soils. Upland rice absorbed much more nitrogen and potassium than were applied in both soils. It is evident that rice absorbed more phosphorus in the Dusky Red Latosols than in the Dark Red Latosols although it only absorbed apparently at most 25% of the amount applied. According to the multiple regression analysis of grain yield in relation to the uptake of

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Table 1 Effect of sowing date on grain yield of 5 upland rice varieties in Londrina and Ponta Grossa in 1976 – 77

Sowing Date	Varieties	Grain yield (14% moist.) kg/ha	
		Londrina (Dusky Red Latosol)	Ponta Grossa (Dark Red Latosol)
Sept. 10	IAC 25	4,049 b*	3,284 a
	EEPG 369	4,398 ab	3,772 a
	Jaguary	4,287 ab	3,019 a
	Batatais	4,756 ab	3,010 a
	IAC 47	5,114 a	3,062 a
Oct. 12	IAC 25	4,323 ab	4,002 ab
	EEPG 369	4,389 a	4,220 a
	Jaguary	3,828 ab	3,024 ab
	Batatais	5,047 a	3,437 ab
	IAC 47	2,767 b	2,688 b
Nov. 10	IAC 25	2,276 ab	3,256 ab
	EEPG 369	1,945 b	3,576 a
	Jaguary	1,146 c	2,427 bc
	Batatais	3,035 a	2,063 c
	IAC 47	(480 d)	2,260 c
Dec. 10	IAC 25	(112 b)	2,096 a
	EEPG 369	(294 b)	2,258 a
	Jaguary	(479 b)	2,095 a
	Batatais	(152 b)	1,164 b
	IAC 47	2,026 a	634 b

* Duncan's range test at 5% level calculated at each sowing date.
Grain yields in parentheses were reduced by drought damage.

the three nutrients as shown in Table 4, phosphorus did not appear to be a limiting factor to grain yield in the Dusky Red Latosols, whereas potassium was a limiting factor in the Dark Red Latosols, when fertilizers $N–P_2O_5–K_2O$ (40–80–40 kg/ha) were applied. However, when data on rice production are combined in both soils, phosphorus uptake as well as potassium uptake in the harvesting stage of rice appeared as limiting factors as shown in the same Table. It may thus be suggested that the supplying capacity of phosphorus and potassium in the two soils created the difference in yield. This is also supported by the fact that the relation between grain yield and potassium and phosphorus uptake resulted in one regression line, indicating different grain production efficiency per unit nitrogen in both soils, as shown in Fig. 1. This can also be suggested from the fact that P/N ratio and K/N ratio of uptake at the harvesting stage of rice differed between the two soils as shown in the same Figure. Thus the lower grain yield in Dark Red Latosols may be due to the fact that the ratio of phosphorus or potassium uptake to nitrogen uptake was lower in the Dark Red Latosols than in the Dusky Red Latosols.

It thus appears that the values of 1,000 grain weight affecting grain yield in the Dusky Red Latosols are controlled by factors such as rainfall rather than nutritional ones. On the other hand, the percentage of filled grains, 1,000 grain weight and number of grains per panicle affecting grain yield in the Dark Red Latosols may be caused by incomplete uptake of phosphorus and potassium.

Table 2 **Mean and standard partial regression coefficient in multiple regression analysis of grain yield for yield components of 5 upland rice varieties grown in Dusky Red Latosols and Dark Red Latosols**

Variables	Mean		Std. partial reg. coefficient	
	Dusky Red Latosol	Dark Red Latosol	Dusky Red Latosol	Dark Red Latosol
Straw yield (kg/ha)	3,620	4,293	0.047	0.261
No. of total grain (1,000/m^2)	15.6	13.3	0.361	-0.071
% of filled grain	89.1	79.5	0.047	0.532**
No. of panicle /m^2	194.6	201.5	0.087	-0.091
No. of grain/panicle	80.2	63.4	-0.039	0.494*
1,000 grain weight (g)	29.3	27.3	0.639*	0.578***
Grain yield (kg/ha)	3,668	2,848		
Multiple regression coefficient			0.932**	0.866**

*, ** Significant at 5 and 1% level respectively from t and F value test.

Table 3 Range of absorption and utilization of nutrients by upland rice grown at Londrina and Ponta Grossa in 1976 – 77

Nutrients	Application (kg/ha)	Absorption of nutrients (kg/ha)			% utilization of nutrients	
		range	mean	cv%	range	mean
			Londrina		(Dusky Red Latosol)	
N	40.0	36.3-95.9	86.4	27.4	91-240	166
P	34.9	3.75-13.7	8.64	33.2	11-39	25
K	33.2	51.2-154.5	94.1	29.0	154-465	283
			Ponta Grossa		(Dark Red Latosol)	
N	40.0	44.9-89.0	72.8	15.1	112-223	189
P	34.9	2.94-8.58	6.92	17.6	8.9-25	21
K	33.2	47.9-125.1	79.7	24.8	144-378	259

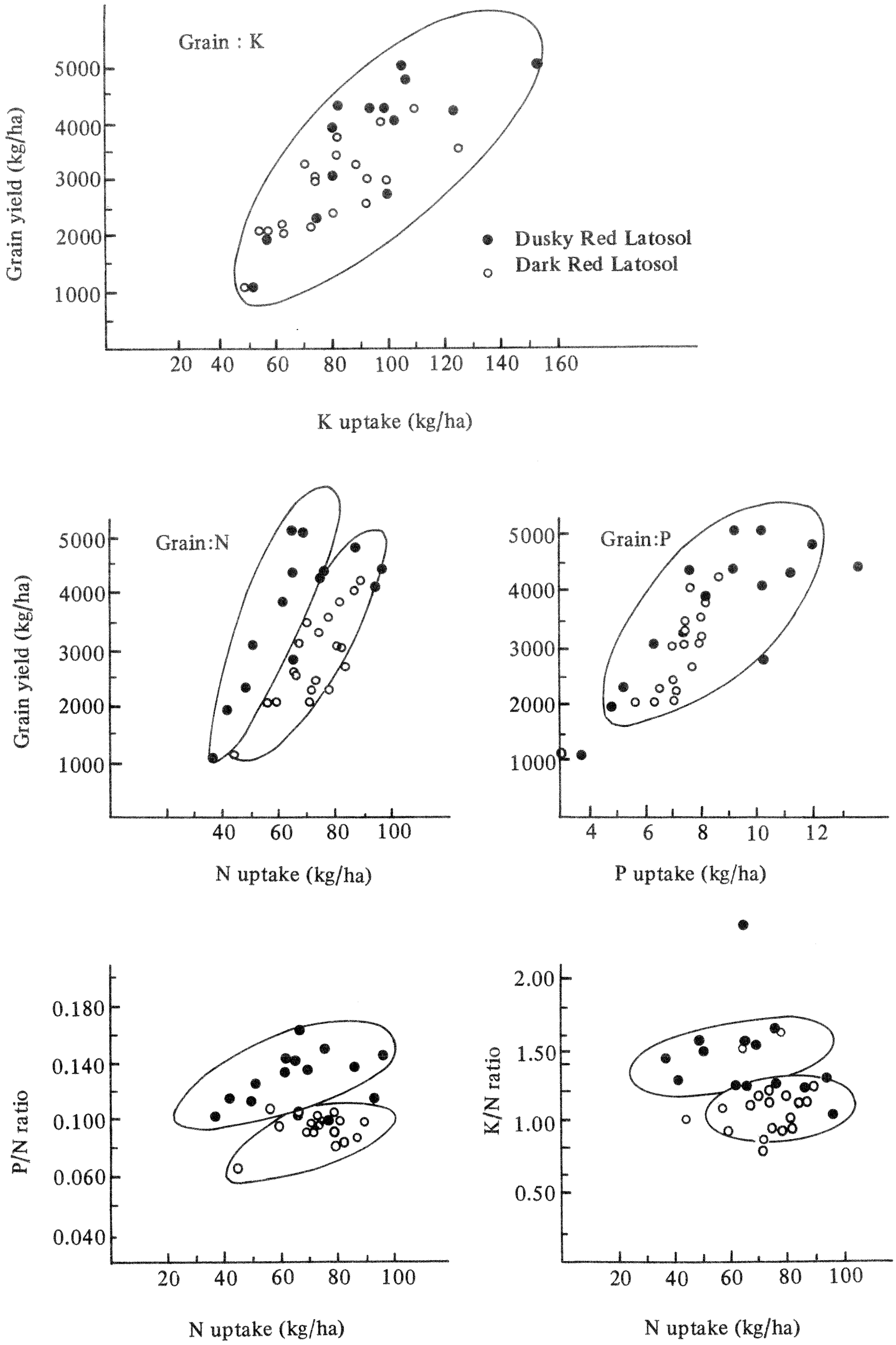


Fig. 1. Relationship between grain yield and total nutrient uptake in upland rice grown in **Dusky Red Latosol and Dark Red Latosol.**

Table 4 Mean and standard partial regression coefficient in multiple regression analysis of grain yield for N, P and K uptake of 5 upland rice varieties in Dusky Red Latosol and Dark Red Latosol

Variables	Mean			Std. partial reg. coefficient		
	Dusky Red Latosol	Dark Red Latosol	Dusky Red and Dark Red Latosol	Dusky Red Latosol	Dark Red Latosol	Dusky Red and Dark Red Latosol
N uptake (kg/ha)	86.5	72.5	70.1	0.471	0.161	0.056
P uptake (kg/ha)	8.65	6.94	7.66	0.035	0.351(*)	0.406*
K uptake (kg/ha)	94.3	79.8	86.0	0.476	0.443*	0.490**
Grain yield (kg/ha)	3,668	2,880	3,214			
Multiple regression coefficient				0.798**	0.861**	0.860**

*, ** Significant at 5 and 1% level respectively from t and F value test.
(*) Significant at 10% level from t value test.

Relation between yield and soil phosphorus forms after superphosphate application

The relation between upland rice growth and phosphorus content and its forms in the above-mentioned Latosols was studied when increasing amounts of superphosphate were applied. Increase in the amounts of superphosphate from 40 to 400 kg P_2O_5/ha with ample nitrogen and potassium supply enabled upland rice grown in a greenhouse in Londrina in pots containing virgin Dusky Red Latosols and Dark Red Latosols, to reach a critical grain yield at the rate of 120 kg/ha, although higher grain yield was obtained in Dusky Red Latosols as in the previous field experiment (Table 5). Upland rice grown in Dusky Red Latosols showed evidently iron deficiency in the early stages of growth. Iron application (30 ppm per dry soil) as Fe-EDTA enabled to correct the deficiency symptoms and resulted in higher grain yield. Iron is known to be sometimes one of the limiting factors of rice culture in Paraná, Brazil (Ohno *et al.*, 1978).

With the increase in the amount of phosphate added, contents of inorganic forms of soil phosphorus determined by the Chang-Jackson procedure (Chang and Jackson, 1957) and a modified method (Peterson and Correy, 1966) increased in both soils as shown in Table 6. The content of iron and calcium phosphates was higher in the Dusky Red Latosols than in the Dark Red Latosols, whereas aluminum phosphate content showed the reverse pattern to a lesser extent. Content of occluded phosphate was much higher in the Dusky Red Latosols, although it did not appear to change with the increase in the amounts of phosphate added in either soil. In this case, total phosphorus content was 529 ppm in the Dusky Red Latosols and 280 ppm in the Dark Red Latosols. On the other hand, superphosphate application mainly increased iron phosphate in the Dusky Red Latosols and aluminum phosphate in the Dark Red Latosols, but only slightly calcium phosphate up to the rate of 200 kg/ha in both soils, as shown in Fig. 2. As for the balance of added phosphorus with respect to the soil-plant relation, as shown in Table 7, the content of residual inorganic phosphorus after uptake by rice was higher in the Dark Red Latosols in spite of the fact that the uptake by rice from added phosphorus was almost identical in both soils up to the rate of 200 kg/ha. Organic phosphorus including undetectable phosphorus showed a reverse pattern.

Table 5 Effect of various amount of phosphorus and iron application on grain and straw yield of upland rice[1] grown in Dusky Red Latosol (Londrina) and Dark Red Latosol (Ponta Grossa)

Amount of superphosphate[2] (P_2O_5 kg/ha)	Growth (dw. g/pot) in Dusky Red Latosol			Growth (dw. g/pot) in Dark Red Latosol		
	panicle	straw	total	panicle	straw	total
Without NPK	13.6 c	21.2	34.8 d	3.6 f	6.0	9.6 e
With NK	14.8 bc	21.3	36.1 d	8.2 e	16.9	25.1 d
40	16.8 bc	26.6	43.4 c	16.2 d	31.7	48.3 c
80	18.8 bc	28.5	47.3 c	22.5 c	37.5	60.1 b
120	32.6 a	37.7	70.3 b	27.4 ab	43.8	71.5 a
200	33.1 a	49.5	82.6 a	25.2 bc	39.8	63.9 b
400	31.4 a	55.8	87.2 a	28.9 a	42.2	71.1 a
120 (-Fe/+Fe)[3]	21.6 b	38.6	60.2 b	29.1 a	42.5	71.6 a
LSD (0.05)	7.29		10.90	3.56		5.73

1) Rice (IAC 25) was grown in pot in greenhouse from December 29, 1977 to May 2, 1987.
2) Each soil was fertilized (basal N-K_2O, 1.0 – 0.5 g/pot and top dressing N-K_2O, 0.5 – 0.3 g/pot 15 days before flowering). Phosphorus was applied as basal fertilizer in the amount indicated in the table for example, 54.6 ppm of P as 120 kg P_2O_5/ha.
3) Fe-EDTA (30 ppm) was applied in Londrina soil except for this treatment and was not applied in Ponta Grossa soil except for this treatment.

Table 6 Phosphorus forms and contents in Dusky Red Latosols (Londrina) and Dark Red Latosols (Ponta Grossa) with various amounts of superphosphate applied (upland rice, pot, 1978)

Superphosphate		Phosphorus content in soil (ppm)						Actual P absorption by rice (ppm/soil)
		Inorganic P			Occluded P		Total	
P_2O_5 kg/ha	P ppm	Al-P	Fe-P	Ca-P	Reductant Sol-P	Al-P		
				Dusky Red Latosol				
0	0	9.4	32.2	20.6	132.8	11.2	206.1	10.0
40	7.8	9.8	31.7	23.2	110.9	9.1	184.7	13.8
80	15.9	9.6	34.9	20.6	141.6	10.0	216.7	13.0
120	23.8	10.0	35.6	22.7	112.3	10.0	190.7	17.4
200	39.7	10.9	37.0	23.7	128.6	10.7	210.9	18.3
400	79.3	19.2	47.0	24.7	107.2	9.1	207.2	35.5
				Dark Red Latosol				
0	0	10.0	27.2	12.4	21.8	7.6	79.0	2.6
40	7.8	10.3	29.0	14.9	26.0	7.4	87.6	5.3
80	15.9	12.3	27.5	13.4	19.9	7.8	80.6	6.1
120	23.8	12.9	28.0	14.9	27.1	7.1	65.1	8.6
200	39.7	15.8	34.1	14.3	30.5	7.6	102.3	10.6
400	79.3	29.7	40.7	20.1	23.7	7.6	121.7	15.5

Table 7 **Phosphorus balance after application of various amounts of phosphorus (upland rice, pot culture with Dusky Red Latosols and Dark Red Latosols)**

Applied-P		Phosphorus balance (ppm)		
P_2O_5 kg/ha	P* ppm (a)	Total inorganic P fixed (b)	Actual P absorption by rice from applied P (c)	Organic and undetectable P (a–b–c)
			Dusky Red Latosol	
40	7.8	2.5	3.8	1.5
80	15.9	2.9	3.1	9.9
120	23.8	6.2	7.5	10.1
200	39.7	9.4	8.3	22.0
400	79.3	28.7	25.7	24.9
			Dark Red Latosol	
40	7.8	4.7	2.7	0.4
80	15.9	3.5	3.5	8.9
120	23.8	6.3	6.1	11.4
200	39.7	14.6	8.1	17.0
400	79.3	40.6	13.0	25.7

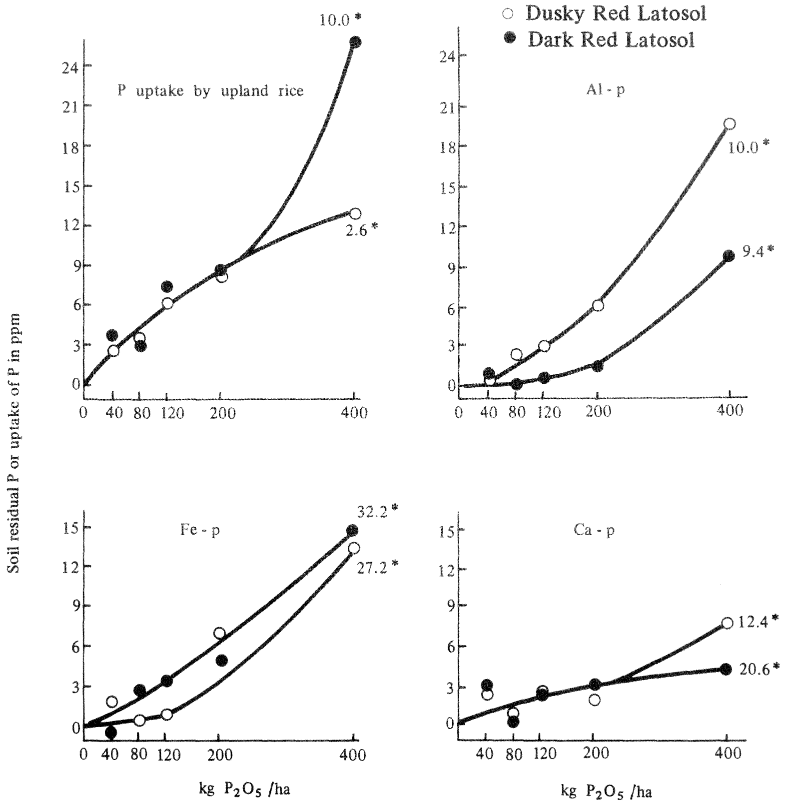
* Actual P absorption was indicated in ppm on the basis of 4.1 kg dry soil (pot culture with Dusky Red Latosol) and 5.1 dry soil (pot culture with Dark Red Latosol).

Upland rice at the harvesting stage in each treatment applied to the Dusky Red Latosols absorbed a much higher quantity of phosphorus than in the Dark Red Latosols, where the uptake was related to the yield ($r = 0.70^*$).* However, it should be noticed that the apparent uptake of phosphorus by rice out of added phosphate took place almost identically in the two soils. It may thus be inferred that the variation in the uptake of phosphorus by rice in the two soils was due to the phosphorus present in soil prior to phosphorus fertilization. It is also suggested that the residual content of the inorganic forms of phosphorus in soil after cultivation of upland rice without application of phosphorus differed between the two soils. Indeed the contents of iron and calcium phosphates were higher in the Dusky Red Latosols, whereas the amount of aluminum phosphate was nearly identical in the two soils as shown in Table 6. This finding may thus suggest that the capacity of upland rice to absorb soil phosphorus, particularly iron and calcium phosphate differs from soil to soil.

Phosphorus uptake of upland rice (0.74**) increased with the increase in the amount of phosphorus application, which was related to the content of soil in iron phosphate (0.93**) and calcium phosphate (0.79**) or inorganic phosphate including the three forms (0.95**), as shown in Table 8. Total yield including panicle and straw was associated significantly with the content of iron phosphate (0.65*) or inorganic phosphate (0.65*). It may thus be suggested that the content of iron phosphate among the inorganic phosphates is a factor more closely related to upland rice growth.

Among the five known procedures for the determination of available phosphorus content in soil, the Olsen method (Olsen and Dean, 1965) was associated with aluminum phosphate content (0.99**) and iron phosphate (0.70*), whereas the Olsen-EDTA (Miyake, 1978) was associated with aluminum phosphate (0.91**) and iron phosphate (0.97**), the Bray I method (Committee of Soil Chemical Analysis, 1975) with aluminum phosphate (0.97**) and iron phosphate (0.69*),

* r, correlation coefficient; *, **, significant at 5 and 1% level respectively.



* Figures show P uptake by rice and contents of P in the soil without P application.

Fig. 2. Apparent residual inorganic P fractions and P uptake by upland rice from fertilizer phosphate, as modified by amounts of superphosphate added in **Dusky Red Latosol and Dark Red Latosol.**

the Bray II method (Committee of Soil Chemical Analysis, 1975) with iron phosphate (0.91**) and calcium phosphate (0.85**), and the Mehlich method (Thomas and Peaslee, 1973) with aluminum phosphate (0.82**), iron phosphate (0.92**) and calcium phosphate (0.61*). The Mehlich (0.79**), the Bray II (0.96**) and the Olsen-EDTA (0.69*) methods which were related to iron phosphate extraction in both soils were highly significantly associated with the phosphorus uptake by upland rice. Besides, available phosphorus determined by the Mehlich (0.60*) and the Olsen-EDTA (0.61*) procedures was related closely to the yield. Thus, this fact supports the evidence that the content of iron phosphate among the inorganic phosphates in both soils shows a better correlation with the growth of upland rice. Accordingly, these results indicate that the Mehlich and the Olsen-EDTA methods are suitable for the determination of available phosphorus in upland rice after superphosphate application.

Table 8 Correlation coefficient matrix of inorganic P, available P extracted by several extractants, P uptake and yield of upland rice in the phosphorus application experiment in Latosols

			P	P	P		Available P				
	Fe-P	Ca-P	Inorg.	Uptake	Applied	Yield	Mehlich	Bray-I	Bray-II	Olsen	Olsen-EDTA
Al-P	.602*	.099	.747**	.394	.866**	.489	.820**	.969**	.378	.991**	.910**
Fe-P	–	.730**	.960**	.926**	.855**	.652*	.920**	.691*	.908**	.701*	.965**
Ca-P	–	–	.709**	.793**	.397	.408	.611*	.257	.853**	.207	.473
Inorganic P	–	–	–	.952**	.895**	.646*	.991**	.822**	.861**	.920**	.950**
P uptake	–	–	–	–	.741**	.700*	.794**	.459	.960**	.517	.693*
P applied	–	–	–	–	–	.795**	.910**	.864**	.670*	.931**	.940**
Yield	–	–	–	–	–	–	.595*	.495	.541	.604*	.610*
Mehlich	–	–	–	–	–	–	–	.987**	.823**	.879**	.974**
Bray-I	–	–	–	–	–	–	–	–	.489	.969**	.937**
Bray-II	–	–	–	–	–	–	–	–	–	.492	.694*
Olsen	–	–	–	–	–	–	–	–	–	–	.943**

*, ** Significant at 5 and 1% level respectively.

Change of soil phosphorus after long-term application of superphosphate

It is important to determine whether phosphorus balance in Latosols shows a relation between the amounts of phosphorus application, uptake by crops and residual contents in soil during various croppings for a long period of time, from the viewpoint of plant nutrition. In various cropping systems, upland rice, soybean, maize, wheat and Napier grass for organic matter accumulation were grown in the Dusky Red Latosols of Londrina from 1975 to 1980. The cropping systems were characterized by the following sequence: crops were grown for 5 years, with (i) continuous cultivation of upland rice for 5 years, (ii) continuous cultivation of soybean for 4 years after 1-year cultivation of upland rice, (iii) a succession of upland rice-soybean, twice after 1-year cultivation of Napier grass, (iv) a succession of upland rice-maize, twice after 1-year cultivation of Napier grass, (v) 1-year cultivation of upland rice and 2-year cultivation of soybean following the cultivation of Napier grass for 1½-year and (vi) 2 years of continuous cultivation of upland rice and 1-year cultivation of maize after 2-year cultivation of Napier grass, including wheat culture in winter of 1977 and 1979. Grain yields of upland rice were unusually low in 1977, 1978 and 1979 because of severe drought damage while the other crops were also affected but to a lesser extent. Accordingly, no differences in grain yield among the various cropping systems were recorded. However, accumulated straw production varied with the cropping systems. In the case of Napier grass and maize the longer the period of cultivation, the higher the production.

Available phosphorus level, determined by the Mehlich method which enables to evaluate the three forms of inorganic phosphate present in the soil, increased gradually from 3.3 ppm in the beginning of the experiment to 7.2 ppm (mean value) at the end of the experiment with the increase in the application of superphosphate, except for the decrease recorded immediately after the cultivation of Napier grass. Contents of aluminum phosphate (0.86**) and iron phosphate (0.84**) among the inorganic forms, as determined by the method of Chang-Jackson, increased significantly with the increment in phosphorus application from 1975 to 1980. Total amount of phosphorus absorbed by crops in the various cropping systems was evidently related to the contents in aluminum phosphate (0.84**) and iron phosphate (0.89**) in soil for the same period. However, contents of calcium phosphate in soil did not seem to be associated with the amount of phosphorus applied nor the uptake by the crops.

It is of interest to determine which fraction of applied phosphorus moved to the soil and accumulated depending on the cropping systems, and in which form of inorganic phosphate it predominated in the Dusky Red Latosols during the 5-year period. As shown in Table 9, amounts of phosphorus applied ranging from 148 – 230 kg P/ha varied with the cropping systems. Also amounts of phosphorus taken up by crop grain depended upon grain yields of crops during the period of study. Contents of aluminum and iron phosphate, among the inorganic forms, evidently increased in the range of 12 – 39 and 23 – 104 kg P/ha respectively. The extent of the increase in the forms of phosphorus paralleled the amount of phosphorus applied. Namely, application of 230 kg P/ha resulted in an increase in aluminum and iron phosphate regardless of the cropping systems, indicating that the content of iron phosphate increased more than that of aluminum phosphate in this soil. Calcium phosphate content showed a significant decrease during the experimental period. Contents of organic phosphate including undetectable forms were high, being proportional to the amount of organic matter from accumulated straw which was returned to the soil. A minor portion of applied phosphate ranging between 4 and 28% was removed by the grains, whereas the major portion in the range of 28 – 82% was returned to the soil as organic forms of phosphate were degraded gradually. Residual inorganic forms of phosphate in the range of 6 – 55% of the applied amount are likely to be transformed to aluminum or iron phosphate in the soil, as indicated by the fact that calcium phosphate content decreased evidently. The higher the amount of applied phosphorus, the higher the level of residual content of iron and aluminum phosphates in soil.

Table 9 Phosphorus balance in various cropping systems from 1975 to 1980 in Dusky Red Latosols of Londrina

		Soil content in P applied (kg P/ha) and accumulated straw					
		Cropping 1[1)]	2	3	4	5	6
Applied P		230 (100)[3)]	230 (100)	230 (100)	230 (100)	196 (100)	148 (100)
Removed P by crop		8 (4)	64 (28)	48 (21)	27 (12)	24 (12)	17 (12)
Soil P	Al-P	33	32	32	39	22	12
	Fe-P	104	88	76	92	50	23
	Ca-P	-10	-14	-10	-26	-30	-26
	Org-P[2)]	95 (41)	60 (26)	84 (36)	98 (43)	130 (66)	122 (82)
	Increased inorg P	127 (55)	106 (46)	98 (43)	105 (46)	42 (22)	9 (6)
Accumulat. straw (kg dw/ha)		28,300	21,800	43,000	54,200	53,800	98,700

1) Cropping systems from 1975 to 1980: 1. continuous cultivation of upland rice (rice) for 5 years, 2. rice and 4-year continuous cultivation of soybean, 3. Napier grass-rice-soybean-rice-soybean, 4. Napier grass-rice-maize-rice-maize, 5. Napier grass-soybean-rice-rice, 6. Napier grass-maize-rice-rice. Wheat was grown in winter of 1977 and 1979.

2) This fraction included organic and undetectable phosphorus.

3) The figures in parentheses indicate distribution percentage of applied phosphorus.

Conclusion

Upland rice was able to grow well in the Dusky Red Latosols used in the experiment despite the relatively small amount of phosphate added. However, deficiency in phosphorus and potassium was a factor limiting the growth of upland rice in the Dark Red Latosols. Grain production efficiency per unit nitrogen uptake in upland rice decreased considerably in the Dark Red Latosols as compared with that in the Dusky Red Latosols, as evidenced by the decrease in uptake of phosphorus and potassium in relation to nitrogen. This finding coincided with the fact that there was a decrease in filled grain percentage and number of grains per panicle among the yield components in the Dark Red Latosols, hence the decrease in yield.

Phosphorus application increased the amount of inorganic phosphate, namely iron phosphate in the Dusky Red Latosols, whereas the amount of calcium phosphate in both soils showed insignificant changes. Although upland rice absorbed higher amounts of phosphorus in the Dusky Red Latosols than in the Dark Red Latosols, apparent phosphorus uptake by rice from added phosphorus was almost equivalent in both soils. Accordingly, it may be suggested that the difference in phosphorus uptake by upland rice originates from the phosphorus which was present prior to phosphorus fertilization. The threshold of phosphorus absorption out of soil by upland rice may vary from soil to soil as shown in the fact that the threshold of iron and calcium phosphate absorption by upland rice was higher in the Dusky Red Latosols than in the Dark Red Latosols, whereas that of aluminum phosphate was practically identical in both soils. Total phosphorus uptake and yield are mostly related to iron phosphate among the inorganic phosphate components. The Mehlich method and the Olsen-EDTA method which evaluate comparatively the content in iron phosphate are suitable for the extraction of available phosphorus following the application of superphosphate for upland rice growth.

Long-term phosphorus application results in phosphorus accumulation in soil as inorganic and organic forms in the Dusky Red Latosols, with a remarkable increase in iron phosphate as well as aluminum phosphate in this soil, while the amounts of calcium phosphate decreased gradually in spite of the application of superphosphate. However, it seems that cropping systems including upland rice, soybean, maize, wheat and Napier grass do not change the content of the inorganic forms of phosphate. The large quantity of organic matter which is returned to the soil as straw increases the part of organic forms of phosphorus in the soil, while the part with residual inorganic forms decreases.

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Discussion

Goswami, N.N. (India): Did you use any tracer in your attempt to prepare a balance sheet of phosphorus under different cropping systems? If not, how could you differentiate between native and applied phosphorus in the process of transformation in soil and also in crop utilization?

Answer: We did not use any tracer in this experiment. Phosphorus content was determined each year before and after crop cultivation in applying the Chang and Jackson method. The value after cultivation in the last year was subtracted from that before cultivation. We use the term "apparent" values when referring to this balance sheet of phosphorus fractions.