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Phosphorus Fertilization in Rice (*Oryza sativa* L) Cultivation Changes Soil P-Fractions

A. L. Shah[1*], J. C. Biswas[2], A. R. M. Solaiman[3] and G. M. Panaullah[1]

[1]*Soil Science Division, Bangladesh Rice Research Institute, Gazipur-1700, Bangladesh*
[2]*Agronomy Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh*
[3]*Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University Gazipur-1703, Bangladesh*
**Corresponding author*

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Abstract

A study was conducted at the BRRI research farm during 2001 to determine the distribution of soil phosphorus (P) fractions in P-deficient rice soil that received varied amount of P as triple super phosphate (TSP) and di-ammonium phosphate (DAP). Solution P ranged from 0.06 to 0.08 mg L^{-1} which was significantly greater in long duration variety (LDV) compared to short duration variety (SDV) at P-control conditions. The increase in $NaHCO_3$-P_i pool was 4.5-35.2% greater with LDV compared to SDV at 30-45 kg P ha^{-1}. There was 7-10% greater NaOH-P_o after growing LDV compared to SDV at larger P doses as TSP. The buildup of NaOH-P_o pool was greater by 18% after growth of SDV compared to LDV when P was added as DAP. The NaOH-P_i fraction increased by about 21-212% with P application compared to P control irrespective of P sources. The larger HCl-P_i fraction buildup (21-152%) took place because of P application either as TSP or DAP, especially with the LDV. The increase in residual-P fraction was 10-158% because of P-fertilization and rice genotypes compared to control. Under P-fertilized conditions, $NaHCO_3$-P_i and NaOH-P_o appeared to have acted as sinks of added P-fertilizer. Cultivation of rice genotypes at 30-40 kg P ha^{-1} under lowland situations further contributes to P buildup in soil which could be utilized in the succeeding crops for profitable farming.

Keywords: Rice genotypes, phosphorus source, aeric haplaquept soil

1. Introduction

Wetland rice (*O. sativa* L) soils are conducive to more P uptake by the plants than aerobic soils. Nonetheless, inadequate P fertilizer application and increased cropping intensity results in P depletion in many soils of Bangladesh (Ali *et al*., 1997) and thus yield reduction in lowland rice could be 50% or more (Saleque *et al*., 1998).

Rice plants can take up available P, but other P fractions such as NaOH extracted inorganic P (P_i) and acid extracted P are also depleted because of crop growth (Saleque and Kirk, 1995). Besides, soil P fractions change because of P fertilizer management and nature of the crops grown. Determination of extractable P_i does not reflect bioavailability of soil-P, which deserves investigation for proper P management in rice production.

The changes in organic P (P_o) and P_i fractions depend on P fertilization (Gahoonia and Nielsen, 2004) and residue management (Kolawole *et al.*, 2004). Moreover, genotypic variations of

cultivated species also contribute to P fraction buildup in soils (Bhadoria *et al.*, 2004). These P fractions give an indication of source-sink relationship in soil-plant systems (Tiessen and Moir, 1993). For example, resin P_i indicates readily available P and NaOH extractable P_i indicates sorbed P (Beck and Sanchez, 1994). The $NaHCO_3$-P_i and NaOH-P_i could be an indicator of sinks for applied P fertilizers (Linquist *et al.*, 1997).

In tropical areas, the P_o contributes significantly to the P nutrition of crops (Sattell and Morris, 1992). Moreover, P_o may be responsible for long-term P availability even though soil tests indicate extreme P deficiency (Ball-Coelho *et al*., 1993). Depletion of native P fertility may occur from different soil pools because of rice cropping without P fertilization. On the other hand, different P fractions can buildup with P application in excess of crop's demand (Reddy *et al*., 2000). Fractionation in P-deficient soils, which receive variable amounts of P fertilizers for cultivation of different rice genotypes, might provide information regarding depletion or accumulation of P in soil. The present investigation was undertaken to understand the effect of the addition of P in different forms along with cultivation of four rice genotypes on soil P depletion or accumulation.

2. Materials and Methods

2.1. Experimental site and soil

The experiment was conducted at the Bangladesh Rice Research Institute, Gazipur during 2001. The soil under experimentation was an Aeric haplaquept (USDA). Physical and chemical characteristics of the initial soils were: pH (1:1.25), 7.2; texture, silty clay; organic carbon (C), 10.5 g kg^{-1}; total nitrogen (N), 1.2 g kg^{-1}, available phosphorus (P), 3.9 mg kg^{-1}; exchangeable potassium (K), 86 mg kg^{-1}; exchangeable Ca, 16.0 g kg^{-1}; available sulfur (S), 16 mg kg^{-1}; available iron (Fe) (oxalate), 1257 mg kg^{-1} and available aluminum (Al) (oxalate), 40 mg kg^{-1}.

Total N was determined by Micro Kjeldahl method (Bremner and Mulvaney, 1982). Organic C by Walkley-Black method, available P (Olsen), exchangeable K and calcium (Ca) (1 N NH_4AOc method) were determined following Black *et al*. (1965). Soil available S was determined by $Ca(H_2PO_4)_2$, 500 ppm P method (Fox *et al*., 1964). Available Al and Fe as oxalate extractable 0.1M oxalic acid and 0.17 M NH_4-oxalate solution were determined according to Khalid *et al*. (1977).

2.2. Design of treatments and soil sampling

Four P-fertilizer rates (0, 15, 30 and 45 kg/ha) TSP and DAP were tested with short and long duration varieties in a factorial RCB design having three replications. All together there were 16 treatment combinations. In total 48 soil samples were collected after two rice cropping seasons. The TSP and DAP were applied basally before transplanting and thoroughly mixed with the soil. The additional N content of DAP was adjusted for with urea-N in the TSP treated plots which was also applied basally. In the dry season, BRRI dhan28 growth duration (GD) of 140 days and BRRI dhan29 (GD of 160 days) were cultivated. In the wet season, rice varieties used were BRRI dhan30 (GD of 140 days) and BRRI dhan33 (GD, 120 days). The plots also received N as urea, K as muriate of potash, S as gypsum and Zn as $ZnSO_4$ in blanket doses at 120-60-10-1 kg ha^{-1}, respectively during the dry season. Only N and K at 80 and 60 kg ha^{-1}, respectively were added during the wet season. Soil samples (0-20 cm depth) were collected using an auger from three spots in each plot, homogenized and air dried for subsequent analyses. Initial soils were also included in the fractionation procedure.

2.3. Extraction procedure

The extraction procedure of Agbenin and Goladi (1998) with minor modification was used in this study. In sequence, 1 g soil was extracted with 30 ml of 0.01 M $CaCl_2$ solution instead of deionizer water. Also a mixture of 1 M HCl and 1 M H_2SO_4 at 1:1 ratio was used for acid P fractionation instead of 0.1 M NaOH used by Agbenin and Goladi (1998). The 0.5 M $NaHCO_3$ and NaOH were used for fractionating labile and moderately labile P forms, respectively. The Ca-bound P was

extracted with 1 M HCl. Phosphorus not recovered in these successive extractions was determined by digesting the soil residue in HNO_3-$HClO_4$ (residual P fraction). The NaOH-P_o fraction was determined by digesting 5 ml of the filtrate from 0.1 M NaOH with 6 ml concentrated H_2SO_4 for one hour. The digest was then cooled and again reheated after adding 5 ml H_2O_2 until the residue became white. Phosphorus was then determined in the digest and was subtracted from NaOH-P_i-P to determine NaOH-P_o pool. Phosphorus in all extract and digest was determined colorimetrically (Murphy and Riley, 1962) after neutralization, when necessary, with dilute HCl and NaOH. The neutrality was indicated by development of a yellow color in presence of para-nitro-phenol indicator.

2.4. Data analysis

Collected data were analyzed using IRRISTAT (1992) and means were compared either by Duncan's New Multiple Range Test (DMRT) or least significant difference (LSD) at 5% level of probability. The relationships among P fractions were determined by Pearson's Product Moment Coefficient correlation (r-test) methods.

3. Results and Discussion

3.1. Solution P

The mean soil solution P varied from 0.06 to 0.08 mg L^{-1}. It was significantly greater with the long duration variety (LDV) compared to the short duration variety (SDV) at P-control conditions (Table 1). However, there was about 14% greater solution P at 45 kg P ha^{-1} compared to P-control (0 kg P) after growing SDV.

The significant variation in solution P at control conditions (0 kg P ha^{-1}) between short duration variety (SDV) and long duration variety (LDV) might be because of differences in P uptake and P balances. There was more P uptake with the LDV compared to the SDV. This greater P uptake by the LDV was related with larger root biomass of the LDV (1.85 g $hill^{-1}$) compared to the SDV (1.56 g $hill^{-1}$). We assumed that the greater root biomass of the LDV provided greater opportunity for P extraction from larger volume of soil including sub-soil and thus leaving some fertilizer P at surface soil resulting in greater P balance. There was comparatively larger P balance with the LDV (11.30 kg ha^{-1}) than the SDV (10.30 kg ha^{-1}) indicating that the genotypic variation contributed to solution P variations. Nielsen *et al*. (2001) also reported that the genotypic variations play an important role in P acquisition from soil. The findings from the present investigation further indicate that the solution P might have renewed many times either from inorganic or organic sources to meet up crop's demand.

3.2. $NaHCO_3$-P_i

Application of P either as TSP or DAP increased $NaHCO_3$-P_i at larger P rates irrespective of varieties (Table 2). The increase was about 3-4 times greater than initial soil (3.75 mg kg^{-1}). The increase in $NaHCO_3$-P_i pool was about 31.50-35.20% with the LDV compared to the SDV when P was applied at 30-45 kg ha^{-1} as TSP. However, it was about 4.50-8.90% when P was added as DAP at 30-45 kg ha^{-1}. In general, rice genotypes significantly influenced this fraction, especially at larger P rates.

There was 16.90-27.60% increase in $NaHCO_3$-P_i pool at 30-45 kg P ha^{-1} as DAP with the SDV compared to P sources and that of 1.30-3.30% as TSP with the LDV. These data indicate that not only P sources influenced soil $NaHCO_3$-P_i pool, but it was also influenced by the cultivated rice genotypes. In a cropping cycle, total P uptake by the SDV (BRRI dhan28 and BRRI dhan33) was 22.90 kg ha^{-1}, but it was 25.50 kg ha^{-1} with the LDV (BRRI dhan29 and BRRI dhan30). This implies that the greater P uptake by the LDV might be from sub-soil, leaving more P at the surface soil. Moreover, the internal P use-efficiency of LDV (300.56 kg kg^{-1}) was greater than SDV (280.30 kg kg^{-1}). These implied that the LDV was not only efficient in P uptake, but they were also efficient in its internal utilization. The increased $NaHCO_3$-P_i fraction in the present investigation further confirms the findings of Buresh *et al*. (1997) who reported that larger application of P as TSP increases $NaHCO_3$-P_i pool in soil.

Table 1. Soil solution-P (mg L^{-1}) as influenced by P-rate and variety.

P-rate (kg ha^{-1})	Variety used		Dose mean	Difference
	Short duration	Long duration		
0	0.06b	0.08[a]	0.07	-0.02**
15	0.07ab	0.07a	0.07	-0.00ns
30	0.07ab	0.07a	0.07	-0.00ns
45	0.08a	0.07a	0.08	0.01ns
Variety mean	0.07	0.08	0.07	-0.01

**Significant at 1% level; ns = non significant; In a column, means followed by a common letter are not significantly different at 5% level by DMRT

Comparison	S.E.D.	LSD (5%)
2-rate*variety means	0.01	0.01

Table 2. $NaHCO_3$-P_i (mg kg^{-1}) as influenced by P-source, P-rate and rice variety.

P-source	P-rate (kg ha^{-1})	Variety		Rate mean	Difference
		Short duration	Long duration		
TSP	0	3.00b	3.62c	3.31	-0.62ns
	15	4.01b	4.73b	4.37	-0.71ns
	30	18.90a	24.86a	21.88	-5.96**
	45	18.20a	24.60a	21.40	-6.40**
DAP	0	3.08c	3.09c	3.08	-0.013ns
	15	4.08c	4.91b	4.49	-0.830ns
	30	22.11b	24.07a	23.09	-1.960**
	45	23.22a	24.27a	23.75	-1.050ns
Variety mean		12.07	14.27	13.17	-2.194

** Significant at 1% level; ns = not significant; In a column under each source, means followed by a common letter are not significantly different at 5% levels by DMRT.

Comparison	S.E.D.	LSD (5%)
2-Source*rate*variety means	0.52	1.05

3.3. NaOH-P_o

The amount of NaOH-P_o fraction was significantly greater at 30-45 kg P ha^{-1} irrespective of P sources and rice varieties grown (Table 3), but it increased by 70-271 mg kg^{-1} fraction compared to initial soil (881 mg kg^{-1}). However, there was 7.10-10.10% larger NaOH-P_o with the LDV compared to the SDV at larger P doses as TSP. It was reverse with DAP in which more than 18% greater NaOH-P_o was recorded with the SDV compared to the LDV. Application of P either as TSP or DAP increased this fraction by 2.20-21.00% compared to P control and irrespective of varieties (Table 3).

Quantitatively we found NaOH-P_o as a major P pool both in fertilized and non-fertilized conditions. We believe that crop residues have contributed to the NaOH-P_o pool build up. Thus, it is implied that NaOH-P_o is a stable pool in soil. This finding further confirms the results of Saleque *et a*l. (2004) who found the largest NaOH-P_o fraction with organic and inorganic P fertilization. The significant positive and negative differences because of P sources with the SDV and the LDV indicate that the LDV contributed more to NaOH-P_o fraction when TSP was used as P source. However, it was reverse with DAP as P source. Although we found

increased organic P fraction because of inorganic P fertilization in a P deficient soil, Agbenin and Goladi (1998) reported decrease in this fraction compared to native uncultivated soil. Saleque *et al*. (2004) also reported no significant increase in NaOH-P_o pool with the addition of organic and inorganic P sources.

3.4. NaOH-P_i

The increase in NaOH-P_i fraction was 25.90-169.40% because of P application and cultivation of SDV compared to P control and that of 21.40-211.60% with LDV (Table 4). This fraction was significantly influenced by rice genotypes, although no response of P sources was observed. The increase of NaOH-P_i pool was 14.50-19.90 mg kg^{-1} compared to initial soil (11.30 mg kg^{-1}).

3.5. Acid-P (HCl-P_i)

Application of P as TSP in consecutive two rice crops increased this fraction by 11.40-74.30% because of growing SDV compared to P control conditions. However, the increase of this fraction was greater (26.09%) with the LDV compared to the SDV (Table 5). This fraction rose from 36 mg kg^{-1} (initial soil) to 39-86 mg kg^{-1} because of P fertilization. Moreover, acid-P fraction was increased by 20.50-61.80% and 25.20-122.20% compared to control because of P application as DAP along with SDV and LDV cultivation, respectively.

The increases in HCl-P_i pool with inorganic P fertilization were probably because of bonding effect of Ca^{2+}. We found larger amounts of Ca (16.03 g kg^{-1}) in experimental soil which might have acted favorably for increased acid P accumulation. Furthermore, slightly greater acid-P accumulation with TSP (52.30 mg kg^{-1}) compared to DAP (49.70 mg kg^{-1}) indicates their variable contribution to inorganic P buildup. Similarly, Xie *et al*. (1993) reported greater P retention as Ca-P compounds with larger P rates. Saleque *et al*. (2004) also reported increased acid P fraction with P fertilization. The percent recovery of added P into Ca-P ranged from 29.70 to 83.80, which indicated that Ca-P was the primary reaction product during P transformation.

Table 3. NaOH-P_o (mg kg^{-1}) as influenced by P-source, P-rate and rice variety.

P-source	P-rate (kg ha^{-1})	Variety		Rate mean	Difference
		Short duration	Long duration		
TSP	0	865.00b	836.30c	850.70	28.70ns
	15	884.70b	893.30b	889.00	-8.70ns
	30	951.00a	1046.70a	998.80	-95.70**
	45	994.00a	1065.00a	1029.50	-71.00**
DAP	0	882.30c	860.00b	871.20	22.30ns
	15	893.30c	886.70b	890.00	6.70ns
	30	1104.00b	935.30a	1019.70	168.70**
	45	1152.00a	962.00a	1056.50	191.00**
Variety mean		965.80	935.50	950.70	30.30

**Significant at 1% level; ns = not significant; In a column under each source, means followed by a common letter are not significantly different at 5% level by DMRT.

Comparison	S.E.D.	LSD (5%)
2-rate*variety means	21.20	43.30

Table 4. NaOH-P_i (mg kg^{-1}) influenced by P-rate and rice variety.

P-rate (kg ha^{-1})	Variety		Rate mean	Difference
	Short duration	Long duration		
0	10.20c	10.00d	10.10	0.20ns
15	12.84b	12.14c	12.49	0.70ns
30	25.79a	27.93b	26.86	-2.14*
45	27.48a	31.16a	29.32	-3.68**
Variety mean	19.08	20.31	19.69	-1.23

**Significant at 1% level; * Significant at 5% level; ns = not significant; In a column, means followed by a common letter are not significantly different at 5% level by DMRT.

Comparison	S.E.D.	LSD (5%)
2-rate*variety means	0.846	1.73

Table 5. Acid-P (mg kg^{-1}) as influenced by P-source, P-rate and rice variety.

P-source	P-rate (kg ha^{-1})	Variety		Rate mean	Difference
		Short duration	Long duration		
TSP	0	35.00c	34.00d	34.50	1.00ns
	15	39.00c	41.30c	40.20	-2.30ns
	30	55.30b	67.00b	61.20	-11.70**
	45	61.00a	86.00a	73.50	-25.00**
DAP	0	34.00d	33.30d	33.70	0.70ns
	15	41.00c	41.70c	41.30	-0.70ns
	30	49.30b	69.00b	59.20	-19.70**
	45	55.00a	74.00a	64.50	-19.00**
Variety mean		46.20	55.80	51.00	-9.60

** Significant at 1% level; ns = not significant; In a column under each P-source, means followed by a common letter are not significantly different at 5% level by DMRT.

Comparison	S.E.D.	LSD (5%)
2-rate*variety means	2.00	4.00

3.6. Residual P

The increase in residual-P fraction was 10-124% because of TSP application in SDV and 17.30-136.30% in LDV compared to control (Table 6). On the other hand, those values were 14.70-138.90% and 17.80-158.20%, respectively for DAP.

There was not much variations in residual-P buildup because of either TSP (59.7 mg kg^{-1}) or DAP (59.40 mg kg^{-1}) application. However, this fraction varied with P levels, especially at larger P rates. This fraction increased up to 87 mg kg^{-1} which was more than twice than that of initial soil (37 mg kg^{-1}). Saleque *et al*. (2004) also reported slight increase in residual-P buildup with increasing P rates. The depletion of such fraction would depend on time of crop cultivation as reported by Ball-Coelho *et al*. (1993).

3.7. Acid-P and $NaHCO_3$-P_i + NaOH-P_i

There was about 52-59% greater acid P than $NaHCO_3$-P_i plus NaOH-P_i because of P-fertilizer application (Fig 1).

Table 6. Residual P (mg kg^{-1}) as influenced by P-source, P-rate and rice variety.

P-source	P-rate (kg ha^{-1})	Variety		Rate mean	Difference
		Short duration	Long duration		
TSP	0	37.00b	34.70c	35.80	2.3ns
	15	40.70b	40.70b	40.70	0.0ns
	30	79.70a	79.70a	79.70	0.0ns
	45	83.00a	82.00a	82.50	1.0ns
DAP	0	36.00d	33.70d	34.80	2.3ns
	15	41.30c	39.70c	40.50	1.7ns
	30	69.30b	80.30b	74.80	-11.0**
	45	86.00a	87.00a	86.50	-1.0ns
Variety mean		59.10	59.10	59.40	-0.60

**Significant at 1% level; ns = not significant; In a column under each source, means followed by a common letter are not significantly different at 5% level by DMRT.

Comparison	S.E.D.	LSD (5%)
2-rate*variety means	1.80	3.70

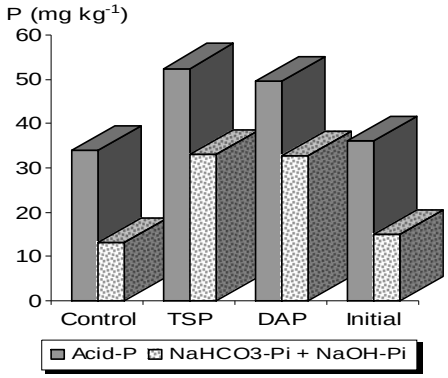

Fig 1. Acid-P and $NaHCO_3$-P_i + NaOH-P_i as changed by different treatments.

The increase in acid-P compared to initial soil was 41.66% whereas; the increase of $NaHCO_3$-P_i + NaOH-P_i was 31.09% compared to initial status.

The decrease in acid-P and $NaHCO_3$-P_i plus NaOH-P_i by 5.97 and 11.45%, respectively under control conditions indicated that mineralization and transformation of P from stable P pools took place. Under control conditions (0 kg P), the significant correlation coefficients of acid-P, $NaHCO_3$-P_i and NaOH-P_i with NaOH-P_o and residual P pools (Table 7) suggest that there was mineralization and transformation for supporting P uptake from soil. However, the stable P pools rather increased with rice cultivation at larger P doses (Table 3 and 6). Saleque *et al.* (2004) also found no significant decrease in NaOH-P_o and residual P pools even under control conditions.

Table 7. Correlation matrix for P-fraction under fertilized condition

	$NaHCO_3$-P_i	NaOH-P_i	NaOH-P_o	Acid-P	Residual-P
Solution-P	0.35ns	-0.68ns	0.39ns	-0.21ns	-0.20ns
$NaHCO_3$-P_i		0.26ns	-0.63ns	0.79*	0.80*
NaOH-P_i			-0.91**	0.79*	0.78*
NaOH-P_o				-0.97**	-0.97**
Acid-P	1.00**				

ns = Non significant; * = Significant at 5% level probability; ** = Significant at 1% level probability

Table 8. Correlation matrix for P-fraction under non-fertilized conditions.

	$NaHCO_3$-P_i	NaOH-P_i	NaOH-P_o	Acid-P	Residual-P
Solution-P	0.99**	-0.99**	-0.99**	-0.99**	-0.99**
$NaHCO_3$-P_i		-1.00**	-1.00**	-1.00**	-1.00**
NaOH-P_i			1.00**	1.00**	1.00**
NaOH-P_o				1.00**	1.00**
Acid-P				1.00**	

* = Significant at 5% level probability; ** = Significant at 1% level probability

3.8. Relationships among P fraction

As under P-fertilized conditions, acid-P showed positive relationship with the residual-P (Table 8). Significant negative relationship of NaOH-P_o fraction with the acid and residual P was also observed. Moreover, there was significant negative relationship between NaOH-P_i and NaOH-P_o pools under P fertilized conditions. Under non P-fertilization conditions, solution-P and $NaHCO_3$-P_i had negative correlations with all studied P fraction except $NaHCO_3$-P_i pool (Table 8). Moreover, other P fractions were highly correlated among themselves.

Generally, wetland rice crops take up P from labile P fractions, NaOH-P_i and acid P pools. Depletion of these fractions may lead to mineralization and transformation of P from stable P pools of either NaOH-P_o or residual P. The positive correlations of solution P with $NaHCO_3$-P_i and NaOH-P_o under fertilized conditions, though not significant, indicate that those fractions might have acted as a sink of added P-fertilizer (Table 7). The increase in $NaHCO_3$-P_i under fertilization condition was also reported by Agbenin and Goladi (1998). Fertilizer P applications increase the soluble or labile P pools in the short term, but this P can be transformed into moderately labile and non-labile P pools within relatively short period of time.

The negative relationships of organic-P pool with acid and residual P fractions indicate that NaOH-P_o fraction might be a sink of transformed P from acid and residual P pools under fertilized conditions. Back and Sanchez (1994) also reported negative correlation ($r = -0.54$) between NaOH-P_o and residual-P fraction. Negative correlations of acid-P with $NaHCO_3$-P_i and solution-P under non-fertilizer conditions indicated its source of P for plant's uptake.

4. Conclusions

There were variable changes in labile P_i pools depending on inorganic P fertilizer application rates and cultivation of different rice genotypes. Under inorganic P fertilization, the increased $NaHCO_3$-P_i, NaOH-P_i and HCl-P_i pools suggest that these pools acted as a transitory sinks of added P. The net increase in labile P_i pools suggest that P-fertilizer had been applied in excess of P requirement for the rice crops. The plant-available P in the non-fertilized system

appears to be organic P pools that replenished labile inorganic-P pools in response to P uptake. It could be further concluded that cultivation of rice at 30-40 kg P ha^{-1} under lowland situations contributes to P buildup which could be utilized by the succeeding crops.

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