

DYNAMICS OF SOIL PHOSPHORUS AND ITS IMPACT ON THE AVAILABILITY OF P IN THE SOILS OF PAJANCOA & RI FARM

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Abstract: Investigations were carried out in the farm soils of PAJANCOA & RI in order to quantify the distribution of Phosphorus (P) in different pools as well as to study the response of paddy crop to P application. For this purpose, the study was conducted in two phases, the first phase being the collection of surface soil samples of PAJANCOA & RI farm, numbering 115, from individual fields and subjecting them to P fractionation. The soil samples were also analyzed for other properties in order to quantify the interrelationship between the P fractions and other soil properties. The second phase of the investigation involved conduct of a pot culture experiment with four types of soils which are differing with their P status namely (i) soils with low levels of both labile and non-labile-P (ii) soils with low levels of labile-P and high levels of non-labile-P (iii) soils with high levels of labile-P and low levels of non-labile-P and (iv) soils with high levels of both labile and non-labile-P and with four doses of P application namely 0, 50, 100 and 150 kg P₂O₅ ha⁻¹. The paddy crop, variety ADT (R) 46 was grown as the test crop. After harvest of paddy crop the soil samples were analysed and correlating the P extracted by different extractants with that of the P fractions, it was noticed that the Olsen-P was positively related to HCl-P and Triacid-P, whereas the Bray-P was more closely related to the NaCl-P fraction. The results were also confirmed by multiple regression and path analysis. Based on the correlation and regression analysis as well as through the path diagram, it was concluded that the P extracted by the Bray II reagent was found to be better related, explains significantly the variations on the yield and uptake parameters and hence adjudged as a suitable reagent to assess the P availability of the PAJANCOA & RI farm soils.

Keywords: Extractants of P, Fractions of P, Soil Properties.

Introduction: India is a boon of nature with more diversification and resources. In the words of the prominent historian V.A. Smith "India is an ethnological museum". Phosphorus is the second most major element among the 17 essential elements for crop growth. The nutrient management in rice is one of the important inputs for the soil health, soil fertility and better yield. Rice production is largely limited by soil P deficiencies in many parts of the world [3], [6] and [12]. In neutral to alkaline soils, P ions will precipitate as calcium phosphorus (Ca-P): dicalcium or octacalcium phosphates, hydroxyl apatite and eventually least soluble apatites and decreases P availability. In acidic soils, the inorganic soil P precipitates as Fe and Al oxide and clay minerals, which are essentially insoluble under aerobic or upland conditions. Indian soils have poor P content.

The scientific background of these phenomena and practical consequences for soil test interpretation and fertilizer application are subject to P dynamics in the soil. Therefore in order to understand the dynamic nature of the P, various extractants can be used for extracting the different forms of P in soils. The Hedley method of fractionation has been widely used to characterize soil P availability. It was reported that there was a decline in NaOH-P with plant P removal. The HCl-P and residual P in the slightly weathered soils declined under cropping. The NaOH-P was the dominant P fraction in the highly weathered soils and declined in response to plant P removal. NaOH-P and NaHCO₃-P are readily available to plant, whereas the HCl-P is unavailable to plants [5].

However, it was realized in the recent time from the soil analytical data and as well from the yield particulars, that there is a vast variation and erratic response to applied P in various fields of PAJANCOA & RI farm. It was also noticed that in some fields there is serious decline in available P levels and some fields have very high values of available P. This necessitated an investigation on the dynamics of soil P in the farm soils of

PAJANCOA & RI with the objectives as, to study the fractions of soil phosphorus in the soils, to quantify the contributions of different fractions of P to the labile phosphorus pool, to optimize the phosphorus dose based on phosphorus dynamics of the soils, to investigate the effect of added phosphorus on the yield and uptake of phosphorus by rice crop.

Materials and Methods: Description of Study Area: The Pandit Jawaharlal Nehru college of Agriculture and Research Institute is about 9 km northwest to Karaikal and lies between $10^{\circ} 49'$ and $11^{\circ} 01'$ N latitude and between $78^{\circ} 43'$ and $79^{\circ} 52'$ E longitude. The study area is situated 4 m above mean sea level (MSL) having the maximum and minimum of 31.95°C and 25.52°C temperatures. Karaikal comes under the eleventh Agro climatic zone of India and it is classified as PC 2 - coastal deltaic alluvial plain zone. Karaikal enjoys a tropical climate and receives an annual average rainfall of 1437.17 mm in 55.83 rainy days in North East Monsoon. The college farm is located in the tail end of Cauvery delta zone, 12 km away from the Bay of Bengal seacoast. The total area of farm in which the institute located is 225 acres. Currently, the eastern farm and western farm is divided into six blocks (A, B, C, D, E and F), occupies an area of 73.95 acres and 25.25 acres respectively. Totally an area of 99.20 acre is now taken as the study area in the present investigation. The detailed soil survey of PAJANCOA & RI farm had indicated the presence of three soil series viz., (i) Sorakudy series. (ii) Thirunallar series (iii) Kottucherry series.

Selection of Field's Soil Samples for Pot Culture Experiment: The surface soil samples (15 cm depth) were collected during summer from PAJANCOA fields, when the fields were fallow, by adopting the standard procedures of soil sample collection and dried, malleted, sieved and preserved for further analysis. The initial soil samples were analyzed for phosphorus fractions. Based on the analytical values of the P fractions, the results were subjected to the descriptive statistics and four fields were selected based on that statistics. The procedure adopted was that the soil samples which recorded lower values than the mean minus standard deviation was considered as low P pool and the values higher than the mean plus standard deviation was considered as high P pool with respect to their labile and non-labile P contents. The fields were divided into low and high levels of labile and non-labile P availability. Since none of the soils contained the labile P at lower level with non-labile P also at lower status, the soil which contained the lowest labile P (but above the mean minus standard deviation values of labile P) was considered as the soil containing both labile and non-labile P at low levels for the purpose of accommodating all possible categories in the experimentation.

Treatment Details: To investigate the dynamics of P, pot culture experiment was conducted during the *samba* season in the pot culture yard of the Department of Soil Science and Agricultural Chemistry, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal.

Factor I: Soil Types:

- S₁: Low level of Labile P and low level of non-labile P (WD6) - LL
 S₂: Low level of Labile P and high level non-labile P (EC4) - LH
 S₃: High level of Labile P and Low level of non-labile P (ED8) - HL
 S₄: High level of Labile P and high level of non-labile P (WB5) - HH
 *Figures in parenthesis refers to the block and field number.

Factor II: Levels of phosphorus (P):

P₁: 0 kg P₂O₅ha⁻¹; P₂: 50 kg P₂O₅ha⁻¹; P₃: 100 kg P₂O₅ha⁻¹; P₄: 150 kg P₂O₅ha⁻¹

The total number of treatments were 16 (4 x 4), number of replications were 3 and 48 pots totally. The design was Completely Randomized Design (CRD).

Pot Culture Experiment: The paddy crop, variety ADT (R) 46 used as the test crop. The capacity of the pot used for the experiment was 20 kg. Each pot was filled with 18 kg of processed soil sample and filled with water. Then, it was mixed with soil to a puddle condition on the day before transplanting. There were 12 pots for each soil type.

The fertilizer dose adopted was 150 kg of N and 50 kg of K₂O ha⁻¹ and the P was applied as per the treatment details furnished above. The common calculated N dose of 140.64 g for 48 pots was applied in the form of urea, in three equal splits i.e., 50 per cent as basal, remaining 2 splits at active tillering stage (28 days after transplanting) and panicle initiation (56 days after transplanting). Potassium was applied at the rate of 35.98 g

for 48 pots in the form of MOP in two equal splits i.e., at basal and at panicle initiation stage. The urea and MOP were dissolved separately in 4900 ml water and a quantity of 100 ml was applied to each pot. Also, zinc sulphate at the rate of 25 kg ZnSO₄ per hectare (19.44 g per pot) was applied as basal to 48 pots. The entire quantity of P was applied as basal at the time of transplanting and thoroughly mixed with the soil along with the N and K fertilizers applied as basal. The different rates of 33.75 g, 67.5 g and 101.25 g P were dissolved in 1200 ml water and applied to 12 pots for each soil types for 50, 100 and 150 kg P₂O₅ ha⁻¹.

Four hills were planted diagonally in each pot. Each hill contained two seedlings. One hill was removed at active tillering stage, another at panicle initiation stage and two were maintained for harvesting stage. The biometric observations were also carried out at these stages. The initial soil samples and the soil samples collected after the crop growth were analyzed for various properties by adopting standard procedures. The extractants Olsen, Bray-I and Bray-II were determined by calorimetric method using 0.5 M NaHCO₃ at pH 8.5 for Olsen-P, 0.03 N and 0.25 N HCl for Bray I-P and 0.03N and 0.1 N HCl [11] and [2]. The different P fractions in soil were determined following a modified P fraction technique, as described by Bolan and Hedley [1].

Statistical Analysis: The yield, biometrical observations and the analytical data obtained in the study were subjected to statistical scrutiny, simple correlation, simple regression, and multiple regression analysis [4]. Path analysis was made to partition and quantify the direct and indirect effects of various fractions of soil P and P extracted by different extractants on the plant and yield parameters [9].

Result: The fields selected for pot culture experiment was shown in figure 1 and the criteria for selecting field were explained in the above section. The soil samples collected for the pot culture experiment were analyzed for various parameters and are presented in Table 1.

The results had shown that the texture of the soils which registered low levels of labile and non-labile-P as well as low levels of labile-P and high levels of non-labile-P was sandy clay. The soil which was classified to contain high levels of labile-P and low levels of non-labile-P was found to possess a sandy loam texture, whereas clay loam was the texture of the soil which was categorized to contain high levels of both labile and non-labile pool. The pH was neutral and the EC indicated non-saline nature of all the soils selected for the experiment. As regards to the Olsen-P content the soil which contained low levels of both labile and non-labile pools was found to record medium status and the remaining three soils registered high status of Olsen-P. The P fractions were found to vary significantly between the soils as the criteria for short listing the soils is based on the relative proportion of labile and non-labile-P.

The P fractions and different extractants were analyzed in the initial and final soil samples. The different extractants and fractions of P showed a significant relationship between them and dynamism in soil properties to different types of selected soils with the different levels of P application (Fig 1). The present investigation had attempted to correlate the fractions of P with the P extracted by different reagents which brought out certain salient conclusions. For instance, the Olsen-P was not related to NaCl-P, negatively related to NaOH-P and positively to HCl-P and Triacid-P. In the case of Bray I-P and Bray II-P it was closely correlated with NaCl-P ($r = 0.572^{**}$ and 0.575^{**} respectively) (Table 2). The above information had brought out the fact that the Olsen-P values cannot be modified just because there are variations in the solution P, but however derives its P from the adsorbed pool of the soil exchange complex thereby resulting in reduction of NaOH-P. A positive correlation of Olsen-P with HCl-P and Triacid-P indicates that the NaCl-P is either precipitated or the Olsen-P is independent of the insoluble P fraction. However, as far as Bray I and Bray II-P are considered there is a good relationship with the NaCl-P. The Olsen reagent derives its P significantly from the non-labile pool and the Bray I and Bray II reagents from both labile and non-labile fractions.

The amount of P extracted by the Olsen reagent from final soil sample was found to increase significantly with the application of P, though the highest level of P application was comparable with 100 kg P₂O₅ ha⁻¹ (Table 3). Among the soils, the soils which were categorized as low with labile-P and high with non-labile-P recorded the highest Olsen-P content and the least was registered in soils containing low levels of labile and non-labile-P. The interaction of P with soil types was not significant.

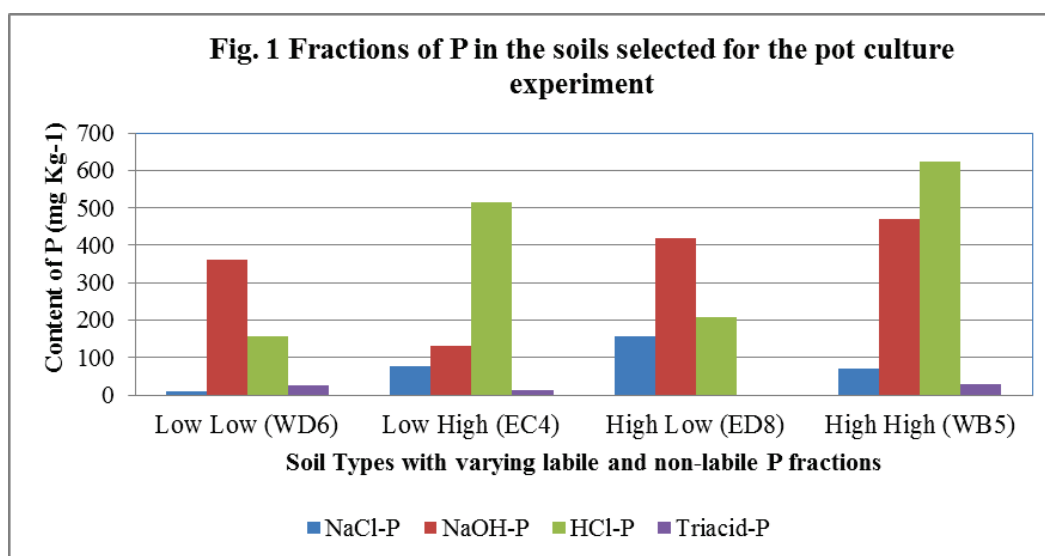


Table 1: Characterization of Surface Soil Samples of PAJANCOA & RI Farm

Sl. No.	Particulars	LL (WD6)*	LH (EC ₄)	HL (ED8)	HH (WB ₅)
1.	Texture	Sandy clay	Sandy clay	Sandy loam	Clay loam
2.	pH	7.81	7.58	6.92	6.06
3.	EC (dS m ⁻¹)	0.12	0.03	0.03	0.05
4.	Olsen-P (kg ha ⁻¹)	18.42	273.80	98.26	103.38
5.	Bray I-P (kg ha ⁻¹)	105.69	59.90	315.74	85.87
6.	Bray II-P (kg ha ⁻¹)	100.70	26.77	231.99	20.39
7.	P fractions (mg kg ⁻¹)				
a.	NaCl-P	8.28	75.39	157.32	71.76
b.	NaOH-P	361.86	132.05	417.65	469.76
c.	HCl-P	155.77	515.64	207.70	623.09
d.	Triacid-P	25.43	11.96	0.00	30.52
	Labile-P	370.14	207.44	574.97	541.52
	Non-labile-P	155.77	515.64	207.70	623.09

Table 2: Results of the Simple Correlation Studies between the Fractions of P and P Extracted By Different Extractants of the Surface Soils of PAJANCOA & RI Farm (n=115)

Sl. No.	Particulars	Olsen-P	Bray I-P	Bray II-P
1.	NaCl-P	0.173 ^{NS}	0.572 ^{**}	0.575 ^{**}
2.	NaOH-P	-0.513 ^{**}	0.029 ^{NS}	-0.101 ^{NS}
3.	HCl-P	0.478 ^{**}	0.018 ^{NS}	0.084 ^{NS}
4.	Triacid-P	0.253 ^{**}	0.008 ^{NS}	0.004 ^{NS}

The P extracted by the Bray I reagent was found to increase significantly with every increase in the levels of P application (Table 3). It was also observed that the highest Bray I-P was associated with the soil which was found to contain high levels of labile-P. The interaction of P with soil type had further indicated that the increase in Bray I-P with P application was observed in soils which contained either low or high levels of both labile and non-labile-P. In the other two soils, the change in Bray I-P was marginal. It had also shown that in control pots the highest Bray I-P was recorded in the soil which contained high levels of labile-P and low levels of non-labile-P. Though this trend was noticed in the presence of applied P it was comparable with the other types of soils.

The content of P extracted by the Bray II reagent was found to be higher in pots which received 150 kg and 100 kg P₂O₅ ha⁻¹ which were comparable (Table 3). Among the soils highest Bray II-P was registered in soils which contained high levels of labile-P and low levels of non-labile-P. The interaction of P with soil type was not significant.

Table 3: Effect of P Levels on the Different Extractants and Fractions (mg kg⁻¹) Content in Soils with Varying Levels of P Fractions

P levels	P Mean						
	Olsen-P	Bray I-P	Bray II-P	NaCl-P	NaOH-P	HCl-P	Triacid-P
0 Kg ha ⁻¹	105.90	63.43	91.75	52.29	269.95	306.48	47.34
50 Kg ha ⁻¹	117.17	71.72	84.30	60.85	400.74	375.05	71.33
100 Kg ha ⁻¹	143.06	91.99	101.58	70.01	333.58	384.26	66.99
150 Kg ha ⁻¹	158.06	107.30	112.23	62.29	374.63	484.31	59.67

Soil Types	S Mean						
	Olsen-P	Bray I-P	Bray II-P	NaCl-P	NaOH-P	HCl-P	Triacid-P
LL	51.32	103.21	105.25	17.77	347.02	190.50	63.94
LH	250.71	42.31	18.29	19.88	278.01	517.59	56.52
HL	114.52	111.23	248.12	132.93	433.16	245.04	41.51
HH	107.62	77.69	18.19	74.86	320.70	596.98	83.38
	P		S		P x S		
	S.E _D	C.D (0.05)	S.E _D	C.D (0.05)	S.E _D	C.D (0.05)	
Olsen-P	11.27	22.96	11.27	22.96	22.55	NS	
Bray I-P	3.08	6.28	3.08	6.28	6.16	12.56	
Bray II-P	8.33	16.97	8.33	16.97	16.66	NS	
NaCl-P	5.85	11.92	5.85	11.92	11.70	23.84	
NaOH-P	21.65	44.09	21.65	44.09	43.29	88.18	
HCl-P	24.86	50.65	24.86	50.65	49.73	101.29	
Triacid-P	11.15	NS	11.15	22.71	22.30	NS	

S.E_D : Standard error, C.D : Critical difference

Attempts were also made in the pot culture experiment to subject the data under the scrutiny of path analysis in order to distinguish the contribution of independent variables directly or indirectly through co-independent variables towards the dependent variable.

The results of path analysis had clearly brought out the fact that the NaCl-P and the Triacid-P had a moderate and high level of negative contribution towards the P extracted by the Olsen reagent, whereas the HCl-P had a positive influence at a higher level (Table 4). It was further noticed that NaCl-P through NaOH-P had a low and negative influence and that of the HCl-P through Triacid-P had a moderate and positive influence on the Olsen-P. The Bray I-P had a positive and moderate contribution from NaCl-P, high level of contribution from NaOH-P and a high level of negative influence from the HCl-P (Table 5). It was further brought out that the Bray I-P was indirectly influenced by the NaCl-P via NaOH-P positively at a low level and by the HCl-P via the Triacid-P. It was noticed that the NaCl-P had a positive and high level of contribution towards the Bray II-P and that of the HCl-P, negative influence (Table 6). The NaCl-P via NaOH-P and the HCl-P through Triacid-P had a positive and a negative influence indirectly towards the Bray II-P.

Table 4: Results of the Path Analysis Showing the Direct and Indirect Effect of the Fractions of P to the P Extracted by the Olsen Reagent in the Soils with Varying Levels of Labile and Non-Labile P

Fractions of P	Direct Effects	Indirect effects				Total of Indirect Effects
		NaCl-P	NaOH-P	HCl-P	Triacid-P	
NaCl-P	-0.226 ^M	-	-0.113 ^L	0.016 ^N	0.036 ^N	-0.061
NaOH-P	0.054 ^N	0.027	-	-0.016 ^N	-0.001 ^N	0.010
HCl-P	0.668 ^H	-0.047	-0.192	--	0.260 ^M	0.021
Triacid-P	-0.390 ^H	0.062	0.008	-0.152	-	-0.082

Table 5: Results of the Path Analysis Showing the Direct and Indirect Effect of the Fractions of P to the P Extracted by the Bray I Reagent in the Soils with Varying Levels of Labile and Non-Labile P

Fractions of P	Direct Effects	Indirect effects				Total of Indirect Effects
		NaCl-P	NaOH-P	HCl-P	Triacid-P	
NaCl-P	0.244 ^M	-	0.122 ^L	-0.017 ^N	-0.039 ^N	0.066
NaOH-P	0.337 ^H	0.169	-	-0.097 ^N	-0.007 ^N	0.065
HCl-P	-0.312 ^H	0.022	0.090	-	-0.122 ^L	-0.010
Triacid-P	0.094 ^N	-0.015	-0.002	0.037	-	0.020

Table 6 Results of the Path Analysis Showing the Direct and Indirect Effect of the Fractions of P to the P Extracted by the Bray II Reagent in the Soils with Varying Levels of Labile and Non-Labile P

Fractions of P	Direct Effects	Indirect effects				Total of Indirect Effects
		NaCl-P	NaOH-P	HCl-P	Triacid-P	
NaCl-P	0.586 ^H	-	0.294 ^M	-0.042 ^N	-0.093 ^N	0.159
NaOH-P	0.073 ^N	0.037	-	-0.021 ^N	-0.002 ^N	0.014
HCl-P	-0.549 ^H	0.039	0.158	-	-0.214 ^M	-0.017
Triacid-P	-0.050 ^N	0.008	0.001	-0.020	-	-0.011

N = Negligible; L = Low; M = Moderate; H = High

Discussion: The theory behind the P fractionation was that the NaCl could extract the solution P content of the soil, the NaOH could extract the adsorbed P content of the exchange complex, the HCl, could solubilise the P in precipitate form, and the Triacid, could dissolve the P in mineral fractions of the soil matter. Among these forms of P, the NaCl extractable P is instantaneously available, the NaOH-P can be made available by a simple exchange phenomena, the HCl-P by the dissolution reactions that may occur in soil and the Triacid-P which can be released only upon weathering. Accordingly the total quantity of the P extracted by NaCl and NaOH is designated as labile-P, the HCl-P as non-labile-P which can be made available slowly and that of the Triacid-P as the unavailable reserve P of the soil. The above nomenclature, in real sense, indicates time frame during which they are available to crop rather than any specific form of P with respect to its interaction with plant. In other words the crop plants ultimately derive certain quantities from all these fractions with varying time frame.

The results of the fractionation studies had indicated that all these fractions were significantly improved due to the addition of P. It is quite expected that the addition of P could result in higher activity of phosphate ions in soil solutions which can be either available for anion exchange if there are sites available for such a phenomena or precipitated as dicalcium and tricalcium phosphate under alkaline condition and iron and aluminum phosphates under acidic environments. Therefore, the increase in all the fractions due to P addition is logical. Among the soils, the soils which registered higher levels of labile and non-labile-P were found to contain maximum amounts of all these fractions since the classification and categorization of the soils was only based on the distribution of these fractions in soil. It is to be understood that all the methods of determination of P availability are deriving their P from all these fractions, but with varying proportions. While there may not be any major differences among the reagents in extracting the NaCl-P fraction, the difference lies in the ability of the given extractant in desorbing the phosphate ion from the exchange complex and/or its ability to dissolve the precipitates of P, either Ca phosphate or Fe and Al phosphates. The simple correlation studies had indicated that the Bray I-P and Bray II-P were positively related to the NaCl-P and NaOH-P but negatively related to HCl-P.

On the other hand the Olsen-P had a significant relationship only with HCl-P. It is to be understood that the Olsen reagent does not contain any acid and therefore it is bound to be not targeting the HCl fraction of P. A positive and significant correlation of Olsen-P with the HCl-P itself is an evidence to show that as the Olsen reagent is not extracting P from the acid soluble fraction there is no decline in its status and therefore a positive relationship. This trend of result had also indicated that the Bray reagents extracts P by dissolving the precipitates of P and increasing the P content in the labile pool in a balanced way and therefore established a negative relationship. The moderately labile Pi (NaOH and HCl-P) pools were considered to buffer the Olsen-P [7] and [8]. Linquist *et al.* (2011) reported that Olsen-P was not correlated with HCl fraction but was correlated positively with the NaCl and NaOH-P indicating the fact that the Olsen-P was effective in extracting the labile pool of P than the non-labile pool. The above conclusion was confirmed by simple regression and

multiple regression analysis. The path analysis also confirms that the Olsen-P had a direct and positive contribution from HCl-P whereas the Bray I and Bray II-P had such contribution from NaCl-P and HCl-P (Table 3, 4 and 5).

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