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Distribution of different phosphorus fractions and their relationship with soil properties in western plain of Rajasthan

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Abstract: Phosphorus fractions and their distribution in soils of western plain of Rajasthan were studied in relation to soil properties. Two hundred nine surface (0-15 cm depth) soil samples collected from seventeen tehsils of three districts (Bikaner, Churu and Jaisalmer) of western plain of Rajasthan were analysed for different physical and chemical properties and different P fractions. Majority of the soils of the study area are sandy in nature and their texture varied from sandy to loam. All the fractions of P gave significant positive correlation with organic carbon, EC, CEC, silt plus clay except Red-P and Ca-P but Total-P, Ca-P, and Olsen-P had significant positive correlation with calcium carbonate except Saloid-P, Fe-P, Red-P, and Org-P. Among the P fractions Saloid-P had significant positive correlation with Fe-P, Red-P, Org-P and Total-P except Ca-P and Olsen-P, and Fe-P had significant positive correlation with Red-P, Org-P, Olsen-P and Total-P except Ca-P, while Red-P had significant negative correlation with Olsen-P. The Ca-P and Olsen-P had significant positive correlation with Total-P, whereas Org-P had significant positive correlation with Olsen-P and Total-P. On the basis of nutrient index soils were found low to medium in available phosphorus. The soils of study area had major portion of their P fraction content in Ca-P *i.e.* 54.61 percent of total-P because of calcareous nature of soil.

Additional key words: *P fractions, soil properties*

Introduction

Phosphorus, like any other plant nutrient is present in soil in two major components *i.e.* organic and inorganic. Organic P, which is mainly confined to the surface layer, is mineralized into inorganic forms but, the plants mainly depend on inorganic P forms for their P requirements. Saloid-P, Al-P, Fe-P and Ca-P fractions are the main source of P supply to the plants. The relative proportion of different forms of inorganic phosphorus depends on various soil characteristics like pH, organic carbon, $CaCO_3$, CEC and texture (Jaggi 1991). Phosphorus is the backbone of balanced fertilization in Indian agriculture. Information on P fertility status of soils is of great importance as it helps to determine the level of P fertilizer to be applied to crops and decide on fertilizer distribution and planning at macro and micro levels. Such information is meager, particularly, in the soils of western plain of Rajasthan and therefore, the present study was undertaken to assess the status of different forms of phosphorus and delineate the area of deficiency or sufficiency of phosphorus in the reported area.

Materials and Methods

Two hundred nine surface soil samples (0-15 cm) collected from irrigated and non-irrigated fields of seventeen tehsils covering three districts (Bikaner, Churu and Jaisalmer) of western plain of Rajasthan were used for the study. The processed soil samples (<2 mm) were analyzed for pH, EC., Organic carbon, $CaCO_3$, CEC, Sand, Silt, Clay and different P fractions by adopting standard procedures. Total P in soil was determined using di-acid digestion method as suggested by Bray and Kurtz (1945). Organic P was determined by using ignition method of Saunders and Williams (1955), as modified by Walker and Adams (1958). The original fractionation procedure for different forms of inorganic P proposed by Chang and Jackson (1957) with some important modifications as summarized by Kuo (1996) and available P by Olsen *et al.* (1954) were used. Simple correlation coefficient analyses between soil properties and fractions of P were computed by standard statistical methods.

Results and Discussion

Total-P

The total P content indicates the reserves of this element in the soil. The total-P content in the soils of Bikaner, Churu, and Jaisalmer district varied from 175.04-296.73 mg kg^{-1}, 173.61-312.16 mg kg^{-1} and 182.58-313.94 mg kg^{-1} with mean value 214.56, 221.30 and 242.91 mg kg^{-1}, respectively (Table 2). The range is quite large which might be due to variation in crop management practices. The overall total P content in the soils of western plain of Rajasthan varied from 173.61-313.94 mg kg^{-1} with mean value 223.88 mg kg^{-1} (Table 2). The minimum content of total-P was recorded as 173.61 mg kg^{-1} in Sujangarh tehsil of Churu district and maximum as 313.94 mg kg^{-1} in Pokran tehsil of Jaisalmer district. The high amount of $CaCO_3$ and organic carbon content of soil increased the amount of total-P in case of Pokran tehsil of Jaisalmer district. The increased amount of $CaCO_3$ in soil decreased significantly saloid-P, Fe-P forms, whereas, Ca-P is increased due to solubilization of $CaCO_3$. The total P content is significantly and positively correlated with EC (r = 0.28**), organic carbon (r = 0.17*) and $CaCO_3$ (r = 0.87**) (Table 3). Similar results were also reported by Gupta and Lattoo (1999) and Trivedi *et al.* (2010). A significant positive association of total P with Sal-P (r = 0.33**), Fe-P (r= 0.40**), Ca-P (r = 0.90**), Org.-P (r = 0.35**) and Olsen-P (0.22**) has been observed in the present investigation (Table 4). The Ca-P was the predominate form of soil phosphorus, and was significantly and positively correlated with total P because of the close association of Ca-P with total-P due to the dominance of Ca-P in soils. Similar results were also reported by Deo Bhatia and Pal (1988), Paramasivan and Udayasoorian (1991) and Patgiri and Dutta (1993). The association between organic P and total P, which is evident because of higher correlation value of organic P and total P, had been reported by many workers such as Chander-Bhan and Harishankar (1973), Singh and Datta (1987), Dongale (1993).

Table 1. Some important physico-chemical properties of soils of western plain of Rajasthan

Soil properties	Districts			Western plain of Rajasthan
	Bikaner	Churu	Jaisalmer	
pH (1:2.5)	7.04-9.57 (8.75)	8.32-9.98 (8.92)	7.19-9.38 (8.64)	7.04-9.98 (8.78)
EC (1:2.5, dSm^{-1})	0.06-0.62 (0.14)	0.03-0.36 (0.09)	0.01-0.85 (0.17)	0.01-0.85 (0.13)
Org. C (%)	0.01-0.23 (0.09)	0.01-0.15 (0.06)	0.01-0.25 (0.07)	0.01-0.25 (0.07)
$CaCO_3$ (%)	0.05-20.30 (6.16)	0.30-26.82 (7.16)	0.10-25.05 (10.92)	0.05-26.82 (7.74)
CEC (cmol (p^+) kg^{-1})	3.64-14.05 (5.88)	3.28-8.12 (4.85)	3.26-6.75 (4.52)	3.26-14.05 (5.21)
Sand (%)	41.77-93.92 (77.81)	55.75-86.92 (77.72)	64.24-86.85 (75.51)	41.77-93.92 (77.24)
Silt (%)	3.51-16.52 (5.68)	3.12-12.59 (4.76)	3.40-10.49 (5.27)	3.12-16.52 (5.74)
Clay (%)	4.52-19.83 (7.90)	4.19-11.86 (6.42)	3.71-9.21 (5.75)	3.71-19.83 (6.88)

Figures in parentheses indicates the mean value of soil properties

Table 2. Distribution of different phosphorus fractions in soils of western plain of Rajasthan

Fractions of P (mg Kg^{-1})	Districts			Western plain of Rajasthan
	Bikaner	Churu	Jaisalmer	
Saloid-P	6.84-20.11 (11.68)	7.02-18.85 (13.23)	7.17-18.46 (12.90)	6.84-20.11 (12.58)
Fe-P	10.65-22.17 (17.03)	12.34-22.54 (17.15)	10.08-30.02 (17.08)	10.08-30.02 (17.09)
Red-P	3.09-8.04 (5.09)	3.08-9.29 (6.14)	3.15-9.23 (5.81)	3.08-9.29 (5.67)
Ca-P	89.21-174.80 (113.17)	87.40-215.71 (121.90)	82.28-198.21 (137.14)	82.28-215.71 (122.26)
Org-P	47.82-94.65 (67.60)	42.69-86.71 (62.87)	43.80-106.85 (69.99)	42.69-106.85 (66.28)
Total-P	175.04-296.73 (214.56)	173.61-312.16 (221.30)	182.58-313.94 (242.91)	173.61-313.94 (223.88)
Olsen-P	1.01-18.89 (7.39)	0.11-4.27 (1.42)	0.98-18.48 (5.35)	0.11-18.89 (4.54)

Figures in parentheses indicates the mean value of P fractions

Table 3. Correlation coefficient of different phosphorus fractions with soil properties

P fractions	pH	E.C	O.C	$CaCO_3$	CEC	Sand	Silt + Clay
Saloid-P	-0.3068**	0.0135	0.2796**	0.0387	0.4585**	-0.3158**	0.4789**
Fe-P	-0.3605**	0.3284**	0.3298**	0.1072	0.3843**	-0.3137**	0.3788**
Red-P	-0.0926	-0.0176	-0.0118	-0.0408	0.0038	-0.0684	0.1255
Ca-P	0.1354	0.0913	-0.1245	0.9343**	-0.1525*	-0.7561**	-0.1426*
Org-P	-0.4132**	0.3320**	0.7090**	0.0177	0.4972**	-0.2176**	0.3758**
Olsen-P	-0.4342**	0.3173**	0.5684**	0.1498*	0.4142**	-0.2645**	0.2482**
Total-P	-0.0736	0.2173**	0.1678*	0.8675**	0.0974	-0.8189**	0.0751

** Significant at 5% level* *** Significant at 1% level*

Table 4. Correlation coefficient between different phosphorus fractions

P fractions	Saloid-P	Fe-P	Red-P	Ca-P	Org-P	Olsen-P	Total-P
Saloid-P	1.0000	0.6056**	0.3993**	0.0411	0.3860**	0.0482	0.3292**
Fe-P		1.0000	0.2874**	0.0723	0.5492**	0.2788**	0.3985**
Red-P			1.0000	-0.0161	0.0425	-0.1518*	0.1112
Ca-P				1.0000	-0.0671	0.0014	0.8988**
Org-P					1.0000	0.6132**	0.3446**
Olsen-P						1.0000	0.2180**
Total-P							1.0000

** Significant at 5% level* *** Significant at 1% level*

Organic–P

Organic P is mainly located in fulvic acid fractions. The soils having high organic matter content generally have high Organic P. The Org-P content in the soils of Bikaner, Churu and Jaisalmer district varied from 47.82-94.65 mg kg^{-1}, 42.69-86.71 mg kg^{-1} and 43.80-106.85 mg kg^{-1} with mean value 67.60, 62.87 and 69.99 mg kg^{-1}, respectively. The overall Org-P content in the soils of western plain of Rajasthan varied from 42.69-106.85 mg kg^{-1} with mean value 66.28 mg kg^{-1} (Table 2). It contributed to 29.61 percent of the Total P in soils of western plain of Rajasthan. The minimum content of Org-P was recorded as 42.69 mg kg^{-1} in Churu tehsil of Churu district and maximum as 106.85 mg kg^{-1} in Pokran tehsil of Jaisalmer district. Organic P had significant positive relationship with Organic carbon (r = 0.71**) (Table 3). It appears that several phosphorus containing organic compounds dominate the soils and on mineralization will be available to crops. Similar observation was recorded by Kothandaraman and Krishnamoorthy (1977) and Viswanatha and Doddamani (1991). Organic P showed significant and positive correlation with Olsen-P (r = 0.61**) and Total-P (r = 0.35**) (Table 4). The association between organic P and total P, which is evident because of higher correlation value of organic P and total P, had been reported by many workers such as Chander-Bhan and Harishankar (1973), Sood and Kanwar (1986) and Dongale (1993). Availability and forms of P in the soil to a large extent are influenced by organic matter application. Some investigations carried out on decomposition of plant and animal residues, revealed that in initial stage of humification, large part of inorganic P gets converted into organic compound but later on when the source of available energy is exhausted, mineralization of Org-P compound was detected. The increase in the availability of P was due to mineralization of Org-P and solubilization of native inorganic P and lesser fixation of added P (Tomar *et al.* 1984).

Inorganic P

The inorganic P exists as the salts of orthophosphoric acid. In general, inorganic P is the predominant form of soil P, constituting 20 to 80% of the total P in the surface layer (Tomar 2003). Inorganic fractions of phosphorus are discussed below under different headings.

Saloid P: The data (Table 2) indicate that saloid P content of the soils of Bikaner, Churu and Jaisalmer district varied from 6.84-20.11 mg kg^{-1}, 7.02-18.85 mg kg^{-1} and 7.17-18.46 mg kg^{-1} with mean value 11.68, 13.23 and 12.90 mg kg^{-1}, respectively. The overall saloid P content in the soils of western plain of Rajasthan varied from 6.84 to 20.11 mg kg^{-1} with mean value 12.58 mg kg^{-1}. The Saloid-P contributed to about 5.62 percent of the Total P in soils of western plain of Rajasthan. The minimum content of Saloid-P was recorded as 6.84 mg kg^{-1} in Kolayat tehsil and maximum of 20.11mg kg^{-1} in Khajuwala tehsil of Bikaner district. The variation in Saloid-P in the studied area soils can be attributed to the variation in clay, organic carbon and available P content of these soils, which is depicted in terms of significant association of Saloid-P with these parameters. The saloid P had significant and positive relationship with organic carbon (r = 0.28**), CEC (r = 0.46**) and silt+clay content (0.48**) (Table 3). The significantly negative correlation between pH and saloid-P (r = -0.31**) may be due to conversion of loosely held surface adsorbed P into less soluble form of P. Similar results were reported in clayey soils of Rajasthan by Sacheti and Saxena (1973). Among the different fractions, saloid P had significant and positive relationship with Fe-P (r = 0.61**), Red-P (r = 0.40**), Org-P (r = 0.39**) and Total P (r = 0.33**) (Table 4). The significant and positive correlation of Saloid-P with Org-P and Total-P indicate that these two forms have profound effect on the content and distribution of Saloid-P. The relatively higher content of Saloid-P in case of Khajuwala tehsil as a result of inorganic fertilization and FYM could be attributed to the transformation of applied P into Saloid-P. The results are in agreement with Sacheti and Saxena (1973), Viswanatha and Doddamani (1991) and Jatav *et al*. (2010).

Fe-P: The Fe-P content in the soils of Bikaner, Churu and Jaisalmer district varied from 10.65-22.17 mg kg^{-1}, 12.34-22.54 mg kg^{-1} and 10.08-30.02 mg kg^{-1} with mean value 17.03, 17.15 and 17.08 mg kg^{-1}, respectively. The Fe-P content in the soils of western plain of Rajasthan varied from 10.08 to 30.02 mg kg^{-1} with mean value 17.09 mg kg^{-1}(Table 2). The Fe-P contributed to 7.63 percent of the Total P in soils of western plain of Rajasthan. The minimum content of Fe-P was recorded as 10.08 mg kg^{-1} in Jaisalmer tehsil and maximum of 30.02 mg kg^{-1} in Pokran tehsil of Jaisalmer district. The high organic carbon content increased the amount of Fe-P in case of Pokran tehsil. Organic carbon had positive relationship with Fe-P. This might be due to the mineralization of organic-P and conversion into iron fraction due to high biological activity in the soils (Sacheti and Saxena 1973). High amount of free $CaCO_3$ is found at high pH at which Fe activity is less to precipitate P into Fe-P. Similar finding were also reported by Chander Bhan and Harishankar (1973) and Viswanatha and Doddamani (1991). The Fe-P had significant and positive relationship with E.C. (r = 0.33**), organic carbon (r = 0.33**), CEC (r = 0.38**) and silt+clay content (r = 0.38**) (Table 3). Chang and Chu (1961) also reported significant and positive correlation between clay and Fe-P, which they attributed to the fact that clay being rich in Fe, there is a possibility for added P or native P to be converted into Fe-P. Among the various fractions, it had significant and positive relationship with Red-P (r = 0.29**), Org-P (r = 0.55**), Olsen P (r = 0.28**) and Total-P (r = 0.40**) except Ca-P, where, the value was non-significant (Table-4). This might be due to low Fe activity as a consequence of its precipitation at higher pH where, the Ca-P usually is the dominant fraction. Similar observation was also made by Mehta *et al.* (1971) and Prasad *et al.* (1996).

Reductant soluble P: The Red-P content of Bikaner, Churu and Jaisalmer district varied from 3.09-8.04 mg

kg^{-1}, 3.08-9.29 mg kg^{-1} and 3.15-9.23 mg kg^{-1} with mean value 5.09, 6.14 and 5.81 mg kg^{-1}, respectively. The Red-P content in the soils of western plain of Rajasthan varied from 3.08-9.29 mg kg^{-1} with mean value 5.67 mg kg^{-1}(Table 2). The Red-P contributed to about 2.53 percent of the Total P in soils of western plain of Rajasthan.The minimum content of Red-P was recorded as 3.08 mg kg^{-1} in Ratangarh tehsil and maximum of 9.29 mg kg^{-1} in Sujangarh tehsil of Churu district. In general, the low value of Red-P was observed in the soil having relatively higher pH and sand content. This might be due to fact that an increase in pH is associated with decrease in iron and aluminum bound P content and rise in the content of calcium bound P and also Red-P is negatively correlated with soil properties. Similar results were also reported by Viswanatha and Doddamani (1991), Sharma and Tripathi (1992) and Trivedi *et al*. (2010). The Red-P showed significant negative correlation with Olsen-P ($r = -0.15^{**}$) (Table-4).

Ca-P: The Ca-P content in the soils of Bikaner, Churu and Jaisalmer district varied from 89.21-174.80 mg kg^{-1}, 87.40-215.71 mg kg^{-1} and 82.28-198.21 mg kg^{-1} with mean value 113.17, 121.90 and 137.14 mg kg^{-1}, respectively. The Ca-P content in the soils of western plain of Rajasthan varied from 82.28-215.71 mg kg^{-1} with mean value 122.26 mg kg^{-1} (Table 2). The minimum content of Ca-P was recorded as 82.28 mg kg^{-1} in Pokran tehsil of Jaisalmer district and maximum of 215.71 mg kg^{-1} in Churu tehsil of Churu district. The Ca-P had significant and positive relationship with $CaCO_3$ ($r = 0.93^{**}$) and negative relationship with CEC ($r = -0.15^{*}$), sand ($r = -0.76^{**}$) and silt+clay content ($r = -0.14^{*}$) (Table 3). Similar observation was also made by Kothandaraman and Krishanamoorthy (1977), Deo-Bhatia and Deo-Pal (1988), Viswanatha and Doddamani (1991) and Sharma and Tripathi (1992). The Ca-P contributed to about 54.61 percent of the Total P in soils of western plain of Rajasthan. The high Ca-P content of western plain of Rajasthan could be attributed to high $CaCO_3$ content indicates greater availability of Ca-P in calcareous soil. On the other hand, highest content of calcium-bound P can be ascribed to calcareous nature of majority of these soils, beside soil reaction, which ranged from 7.04-9.98 and within this range, the calcium bound P is normally the dominant inorganic soil P fraction. The Ca-P was the predominant form of soil phosphorus, and was significant and positive correlated with Total P ($r = 0.90^{**}$) (Table 4). The close association of Ca-P with Total-P was due to the dominance of Ca-P in soils. Similar results were also reported by Deo Bhatia and Pal (1988), Paramasivan and Udayasoorian (1991) and Patgiri and Dutta (1993).

Delineation of phosphorus deficient and sufficient area

Plant roots absorb phosphorus in the forms of $H_2PO_4^-$, HPO_4^{2-} ions from the soil solution. Keeping in view this fact, the soil under study may be classified as low (< 10 kg ha^{-1}), medium (10-25 kg ha^{-1}), and high (>25 kg ha^{-1}) category as per the categorization suggested by Velayutham and Bhattacharayya (2000) for available P. According to these categories, out of 209 soil samples of the studied area, 64.6 percent samples were low, 25.4 percent medium and 10.1percent were high in available phosphorus (Table 5). The maximum deficiency was observed in Churu district followed by Jaisalmer and Bikaner districts, because of relatively high pH, $CaCO_3$ content and high P fixation capacity with low organic carbon content in these soils. Thus 64.59 percent of soils of western plain of Rajasthan are likely to respond to phosphorus fertilization.

Table 5. Phosphorus fertility status in soils of western plain of Rajasthan

Tehsils	Number of Samples analysed	Per cent samples in the indicated categories			Nutrient Index
		Low (< 10 kg ha^{-1})	Medium (10-25 kg ha^{-1})	High (>25 kg ha^{-1})	
Bikaner district					
Bikaner	10	-	100	-	2.00
Khajuwala	05	-	20	80	2.80
Pugal	07	-	-	100	3.00
Chhatargarh	06	-	-	100	3.00
Nokha	13	38.46	61.54	-	1.62
Dungargarh	09	-	100	-	2.00
Kolayat	15	93.33	6.67	-	1.07
Lunkaransar	12	58.33	41.67	-	1.42
Total samples	**77**	**33.77**	**44.16**	**22.07**	**1.88**
Churu district					
Churu	10	100	-	-	1.00
Ratangarh	10	100	-	-	1.00
Sardarshahar	17	100	-	-	1.00
Rajgarh	22	100	-	-	1.00
Sujangarh	15	100	-	-	1.00
Taranagar	09	100	-	-	1.00
Total samples	**83**	**100**	**-**	**-**	**1.00**
Jaisalmer district					
Jaisalmer	18	72.22	27.78	-	1.28
Fatehgarh	10	100	-	-	1.00
Pokran	21	14.29	66.67	19.04	2.05
Total samples	**49**	**53.06**	**38.78**	**8.16**	**1.52**
Total samples of western plain of Rajasthan	**209**	**64.59**	**25.36**	**10.05**	**1.45**

Nutrient index (NI): NI < 1.67 Low, NI 1.67-2.33 Medium, NI >2.33 High

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