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Multi-location assessment of variability and relationships of phosphorus fixation, fractions, availability and recovery under high P Alfisols

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ABSTRACT

A study was conducted to assess P-fixation, P-fractions and availability of P under selected high P soils under semi-arid Alfisols in Nizamabad of Telangana and Guntur and Kurnool districts of Andhra Pradesh. A survey was carried out for recording occurrence of high-P soils in Varni, Mangalagiri and Velugodu locations of Nizamabad, Guntur and Kurnool, respectively. The survey revealed that high-P soils in these three locations were 98, 71 and 77%, respectively. Three soil samples from each location (categorized into high, very high and extremely high for soil P) were selected and studied under laboratory conditions. The soils were studied for P-fractions, P-fixation and recovery of applied P. Within each location, soils exhibited an increase in the amount of each fraction of P with increasing soil P. An incubation study was undertaken with P^{32} isotope to understand available and recovery of applied P. Observations were recorded at 3 contact periods *viz.,* 15, 30 and 45 days after incubation (DAI). The soil P decreased with increase in DAI under the 3 soil fertility situations. The percent P derived from fertilizer (PDFF) in different locations increased with increase in P levels in all soils with increase in DAI. Within each soil, PDFF decreased with increase in initial P. The percent recovery of P was higher at Velugodu (52%), followed by Mangalagiri (50%) and Varni (39%) when compared between 25 to 100% recommended P application. The recovery of P increased with increase in P application at all locations. Based on the study, the high P soils could be efficiently managed by assessing the relationships of phosphorus fixation, availability, fertilizer application and recovery under Alfisols.

1. INTRODUCTION

The importance of P fertilizers in crop production is undisputable. Efforts were always made to enhance the use efficiency of not only P but also other costly nutrient inputs to economize the cost of cultivation and conserve resources. Despite fertilizer price policy of Government of India, continuous use of P fertilizer is likely to increase the P accumulation in top layers of soils. The P fertilizer consumption in the country has increased tremendously over decades. The share of P in total fertilizers consumed has increased over years. In Andhra Pradesh, the DAP consumption in Nizamabad, Guntur and Kurnool increased by 395, 78 and 36%, respectively during 2001-02 and 2008-09. The dryland agriculture locations where crop yield is low but received regular P in low quantities are also areas of P-accumulation. If P fertilizer is reduced in P-accumulated areas, it would help for profitable agriculture and reduce dependency on imports. Deb (2009) indicated that unless P-fixing sites are saturated to a certain degree, availability of native and applied P will not increase. The occurrence of high P soil will have implications of (i) saving costly P fertilizer without sacrificing current production; (ii) interference with other soil nutrients. Abrol *et al.* (2015) suggested that there is a significant accumulation of P in soils whenever optimal NPK was applied for different crops.

In Northern Telangana, majority of soils surveyed had high amount of available P in rice-sugarcane belts. The occurrence of high P soils in Nizamabad was 99% (out of

522 samples), compared to Kurnool with 45% (out of 522 samples) and Guntur with 97% (out of 402 samples). Phosphorus is generally bound to aluminum (A1-P), iron (Fe-P) and these forms constitute major active forms of inorganic P in soils. Deb (2009) in his isotope aided research for enhanced use efficiency of P and Zn, stated that unless P-fixing sites are saturated to a certain degree, availability of native and applied P will not increase. Deo and Rahul (1972) expressed that in calcareous soils of Rajasthan, Ca-P constituted major fraction *i.e.* 44 to 52% of total inorganic P, followed by A1-P (9 to 17%) and Fe-P (3 to 6%). They observed that A1-P and adsorbed P were significantly correlated with available P extracted by Olsen and Bray's methods.

In Vertisols, most dominant P fraction was Ca-P, followed by Fe-P and Al-P; while in Alfsols, the order was Fe-P>Ca-P>Al-P. Brown (1981) reported that though Ca-P was a dominant fraction in calcareous black soils, its contribution to available P was lower than Fe-P. He attributed this to the fact that Ca-P remained in unavailable form, insoluble carbonate apatite. Tomar *et al.* (1984) conducted an experiment on calcareous soils and found that Fe-P contributed to available P, followed by Al-P and saloid P. Haden *et al.* (2007) conducted an incubation study in New York on factors affecting the change in soil P following manure and fertilizer application where they found that for all soil tests, P levels increased with fertilizer application but decreased throughout at 60 days incubation. The magnitude by which time affected each soil P pool and time point at which significant reductions were observed differed among soil tests.

Trivedi *et al.* (2010) observed that Olsen-P, Fe-P, Al-P, Red-P and total-P decreased with increasing depth, where as Ca-P was lower in surface layers and increased with depth. The Ca-P was more predominant P fraction, followed by reductant soluble-P, Al-P and Fe-P in soil pH range of 6.8 to 10.1. Lan *et al.* (2012) conducted an experiment to study P availability and rice grain yield in response to long-term fertilization for 26 years. Most soil inorganic P fractions decreased with time due to continuous depletion by rice plants in the non-fertilized treatment, while inorganic P-fraction increased with time in fertilizer treatments due to continued supply of P to soil. Saha *et al.* (2013) conducted a long-term experiment on pearl millet-wheat sequence at Hisar. In this study on inorganic P fractions, Ca-P was the dominant fraction (78.7%), followed by A1-P (10.1%), Fe-P (7.9%) and saloid-P (3.3%). Increasing levels of P application increased significantly saloid-P, A1-P, Fe-P and Ca-P over lower levels of P application. The present investigation was taken up with the objective to study the extent of P accumulated soils and their characteristics in 3 locations representing 3 regions of erstwhile Andhra Pradesh.

2. MATERIALS AND METHODS

Three locations of Varni in Nizamabad, Mangalagiri in Guntur and Velugodu in Kurnool were selected for collection of soil samples. These areas were selected keeping in view of intense cropping and fertilizer consumption in the districts. Grid based soil sampling was done from these locations. Soil samples were analyzed by following standard procedures for pH, electrical conductivity (EC), organic carbon, calcium carbonate, available N, P, K, zinc, copper, iron and manganese.

P Fixation Characteristics and Fractions

Nine soil samples (3 each from 3 locations) were collected and employed for P-fixation and P-fraction study. Procedure of Waugh and Fitts (1966) was followed for P fixation study. The initial soil characteristics are given in Table 1. Standard

Table: 1
Physico-chemical and chemical properties of soils from 3 locations

Sample No.	pH	EC (dS m^{-1})	$CaCO_3$ (%)	Available macronutrients (kg ha^{-1})			Available micronutrients (mg kg^{-1})			
				N	P_2O_5	K_2O	Zn	Fe	Cu	Mn
N 38	7.6	0.126	2.38	276	41	403	0.55	5.71	1.58	5.47
N 41	7.8	0.172	2.46	276	93	296	0.68	5.24	1.54	5.34
N 45	7.8	0.176	2.63	263	151	645	0.48	6.42	1.78	6.16
G 4	7.5	0.082	2.23	188	47	548	0.40	9.37	1.16	5.00
G 25	7.7	0.136	2.61	364	90	761	0.64	4.32	1.55	5.79
G 19	7.8	0.168	2.68	138	122	641	0.62	7.90	1.45	5.80
K 4	7.9	0.095	2.35	238	51	504	0.57	4.61	1.64	5.87
K 13	7.2	0.302	2.52	239	95	527	0.85	7.31	1.57	5.89
K 25	6.9	0.175	2.64	288	122	650	0.62	7.86	1.33	5.90
Mean	7.6	0.159	2.50	252	90	553	0.60	6.53	1.51	5.67
CV	4.4	40.3	6.2	25.3	42.3	25.6	21.2	26.1	11.9	6.3

CV: Coefficient of variation (%), N: Nizamabad, G: Guntur, K: Karimnagar

P stock solution (350 ml with pure anhydrous monocalcium phosphate) tagged with ^{32}P was prepared. Out of this solution, different concentrations equivalent to 25, 50, 75 and 100% RDP were prepared by dilution. Eleven soil samples (9 survey samples, 3 from each location and 2 samples from 2 experimental fields), 2g each were weighed (in triplicate) in 100 ml conical flasks. Then added 1, 2, 3 and 4 ml of standard P solution that represents 25, 50, 75 and 100% RDP samples in conical flasks. The flasks were plugged with cotton wool and allowed to incubate at room temperature for 45 days. P is extracted by Olsen's method and estimated calorimetrically at 15, 30 and 45 DAI. For radio assay, 5 ml of above aliquot was taken into micro beakers and dried under infrared lamp. ^{32}P activity of dried residue in micro beakers was counted using GM counter (Model RCS 4027A) along with fertilizer standards.

The calculations for radio assaying were done as:

$$\text{Specific activity of the standard} = \frac{\text{Net count per unit time in aliquot of the standard}}{\text{Total P in aliquot (ppm) of the standard}}$$

$$\text{Specific activity of the sample} = \frac{\text{Net count per unit time in sample aliquot}}{\text{Total P in aliquot (ppm) of the sample}}$$

$$\text{P derived from fertilizer (PDFF, \%)} = \frac{\text{Specific activity of sample}}{\text{Specific activity of the standard}}$$

$$\text{P recovery (\%)} = \frac{\text{Specific activity of the standard \% PDFF x total P extracted from soil}}{\text{Rate of P fertilizer applied (mg)}}$$

Inorganic P fractions

Methods described by Peterson and Corey (1966) were followed in estimation of inorganic P fractions of soils. One gram of soil was taken in a 100 ml polypropylene centrifuge tube and 50 ml of 1N NH_4Cl was added and shaken for 20 minutes. The suspension was centrifuged at 2000 rpm for 10 minutes. The supernatant solution was used to estimate saloid P using ascorbic acid reagent. Fifty ml of 0.5N NH_4F was added to the residue obtained after separation of saloid P, and shaken for one hour and centrifuged for 10 minutes at 2000 rpm. From the supernatant solution, 5 ml of aliquot was used to estimate Al-P with ascorbic acid reagent. The soil residue in the centrifuge was washed twice with 25 ml saturated NaCl. Then 50 ml of 0.1N NaOH was added and shaken for 17 hours. The suspension was centrifuged for 15 minutes at 2400 rpm and supernatant solution was decanted, which was used for Fe-P determination with ascorbic acid.

The soil residue after extraction of Fe-P was given two successive centrifuge washings with saturated NaCl (25 ml). Suspended soil solution in 25 ml of 0.3M $Na_2C_6H_5O_7.2H_2O$, added 1 g of solid $Na_2S_2O_4$ and shaken for 5 minutes. Heated the suspension in a water bath at 75 to 80^0C following dilution to 50 ml volume and centrifuged at 2000 rpm for 10 minutes. Transferred supernatant solution into extraction tube with constant suction with pipette. Added 1.5 ml of 0.25M $KMnO_4$ to oxidize the dithionate and citrate. After two minutes, added 3 ml of ammonium molybdate sulphuric acid reagent, followed by 10 ml of isobutyl alcohol. Dispersed the alcohol through aqueous phase by inverting extraction tubes 25 times and took 5 ml aliquot from alcohol phase for estimation of red-P at 660 nm. The soil residue was shaken for 1 hour with 50 ml of 0.5N H_2SO_4 and centrifuged for 10 minutes at 2000 rpm. From supernatant solution, Ca-P was determined with ascorbic acid.

Availability of applied P in high P soils

In order to understand availability and recovery of applied P at different rates, an incubation study was undertaken with the same soils that were used for P fixation study. The study was conducted with 9 soils comprising of 3 each from Nizamabad, Guntur and Kurnool with 2 replications. The recommended dose of P_2O_5 was 60 kg ha^{-1}. The levels of P_2O_5 were 0, 25, 50, 75 and 100% recommended P, while contact periods were 15, 30 and 45 days. The activity of P used was 0.4 mCi g^{-1} of P_2O_5. Fifty grams of soil from each of the 9 samples in required numbers were taken in 200 ml polythene bottles. Required quantities of P were introduced after tagging with P activity as per treatments. Soil samples were maintained at field capacity by regularly checking weights. Samples were drawn after stipulated contact periods and analyzed for available P_2O_5 and radio assay was carried out in the extracts as per standard procedures.

Soil analysis

The pH of samples was determined in 1:2.5 soil water suspension by using pH meter with glass electrode (Jackson, 1973). EC was determined in 1:2.5 soil water extract with digital conductivity meter and expressed in dS m^{-1} (Jackson, 1973). Organic carbon (%) was determined by Walkley and Black (1934) rapid titration method. Available N (kg ha^{-1}) was estimated by alkaline permanganate method (Subbaiah and

Asija, 1956), while P (kg ha^{-1}) was extracted by Olsen *et al.* (1954) method. Available K (kg ha^{-1}) was extracted by ammonium acetate method (Jackson, 1973). Available zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) were estimated by atomic absorption spectrophotometer (Lindsay and Norvell, 1978) and expressed as mg kg^{-1}. Initial calcium carbonate (%) was measured by rapid titration method (Puri, 1930).

3. RESULTS AND DISCUSSION

Survey and Mapping of Soils

A minimum number of 30 samples were collected in each location and analyzed for available P and other characteristics. The pH of Varni soils ranged from 6.7 to 8.1 and was devoid of salt problem due to EC in the range of 0.11 to 0.48 dS m^{-1}. These soils were low in N (85%) and K_2O was medium to high, while P_2O_5 was high. At Mangalagiri, pH ranged from 7.1 to 8.5, EC ranged from 0.082 to 0.819 dS m^{-1}, N ranged from 138 to 364 kg ha^{-1} and K_2O ranged from 220 to 766 kg ha^{-1}. The P_2O_5 ranged from 41 to 196 kg ha^{-1}.

The mean pH at Velugodu was 7.6, while EC ranged from 0.065 to 0.347. The N content ranged from 113 to 326 kg ha^{-1}, while K_2O ranged from 218 to 673 kg ha^{-1} and P_2O_5 ranged from 24 to 169 kg ha^{-1}. The three locations were selected in anticipation of such phenomenon based on enterprising farming community using high P inputs for regular and high value crops. The major crops in Varni were sugarcane and rice, compared to chilli and cotton at Mangalagiri, while rice was the predominant crop at Velugodu. The extent of high P soils in Varni was 98%, while it was 71 and 77% in Mangalagiri and Velugodu, respectively. The observations indicated that the mean P_2O_5 at Varni was very high (130 kg ha^{-1}) where as Mangalagiri and Velugodu soils were similar with 95 kg ha^{-1}. The descriptive statistics of parameters are given in Table 2.

None of the samples were recording low and medium soil P fertility. Traditionally, these medium to heavy textured soils, upon receipt of high input fertilization had gradually become P accumulated soils over years. The survey was carried out during summer 2009. The classification of Muhr *et al.* (1965) indicated that P_2O_5 >57 kg ha^{-1} was designated as high category of P fertility. The surveyed soils had much higher P_2O_5 content > 57 kg ha^{-1}. Higher P_2O_5 within this high P category would be the implication regarding P-requirement of crops, nutrient interaction etc. In the absence of any sub-categorization within high P fertility, an attempt was made to categorize high P soils into different sub-groups within high P_2O_5 category in the range of 57-100, 100-125, 125-150 and >150 kg ha^{-1}. Such a classification may help in studying the extent of reduction of P application to crops in high P soils.

P-fixation Characteristics of Selected Soils

The observations of P-fixation characteristics of each location indicated that there was not much variation in P-fixation with increase in P application. However, soils of Guntur had more reduction in P-fixation from 77.6 to 70.3%, as P_2O_5 increased from 47 to 122 kg ha^{-1}. This was followed by Velugodu where P-fixation capacity decreased from 74.6 to 70.2% as P_2O_5 increased from 51 to 122 kg ha^{-1}. Though available P_2O_5 increased from 41 to 151 kg ha^{-1} at Varni, the reduction in P-fixation was only from 73.4 to 71.5%. The P-fixation capacity of soils was not exclusively dependent on available P_2O_5. It is governed by soil clay content in heavy and sediment soils. In calcareous soils dominant with $CaCO_3$, P-fixation was relatively higher (Al-Rohiley *et al.,* 2013). The soils having P_2O_5 of 122 to 151 kg ha^{-1} have shown mean P-

Table: 2
Descriptive statistics of soil parameters at different locations

Location	pH	EC	N	P_2O_5	K_2O	Zn	Fe	Cu	Mn
Varni									
Range	6.7-8.1	0.106-0.480	201-264	41-181	202-685	0.40-0.75	4.92-8.53	0.92-1.98	4.69-6.87
Mean	7.6	0.219	261	130	352	0.6	6.4	1.52	5.7
CV	3.5	37.6	10.8	19.6	28.3	15.1	10.8	16.9	5.3
Mangalagiri									
Range	7.1 - 8.5	0.082 - 0.819	138 - 364	41-196	220-766	0.40-1.26	4.02-9.37	1.04-1.78	4.77- 5.83
Mean	7.8	0.239	227	95	584	0.66	6.22	1.51	5.41
CV	3.7	68.2	20.1	50.2	24.9	23.7	24.4	13.2	5.8
Velugodu									
Range	6.5-9.0	0.065-0.347	113-326	24-169	218-673	0.39-0.90	4.36-9.97	1.16-2.36	5.59-5.98
Mean	7.6	0.174	227	95	449	0.66	6.66	1.73	5.90
CV	7.4	38.3	19.1	41.5	31.5	22.1	22.7	17.5	1.2

CV: Coefficient of variation (%)

fixation capacity of 70.7%. The P-fixation capacity of soils having initial P_2O_5 of 90 to 95 kg ha^{-1} and 122 to 151 kg ha^{-1} did not differ much as it was around 70 to 71%. Thus in black soils, P-fixation continues to be high though available P_2O_5 was about 151 kg ha^{-1}.

P-fractions of Selected Soils

The P-fractions obtained from selected samples are given in Table 3. The results indicated that mean saloid P content ranged from 12.6 to 14.3 mg kg^{-1} soil. Likewise Al-P, Fe-P, Red-P and Ca-P ranged from 31.6 to 32.6, 29.0 to 30.8, 20.0 to 21.4 and 107.0 to 110.7 mg kg^{-1} soil, respectively. There was a narrow range in the parameters at 3 locations. When data was perceived separately for medium (S1 of all locations) soils, for soils having P_2O_5 of 90-95 kg ha^{-1} and 122-151 kg ha^{-1}, a different picture was observed. All P-fractions increased with increase in P fertility. It is important to understand the forms of P-fractions and their relative content in P accumulated soils as it determines the fate of release of accumulated P. The attempt made as part of this investigation revealed that not only the extent of P-fractions increased with increasing soil P, but almost all had similar magnitude across locations as available P_2O_5 increased to 90 to 95 kg ha^{-1} and 122 to 151 kg ha^{-1}.

Effect of P Application on Soil P

The effect of applied P on soil P after different days of incubation are given in Table 4. At Varni, there was a significant difference among soils, P levels and DAI in influencing soil P. The mean P_2O_5 significantly increased from 51 to 164 kg ha^{-1} over P and DAI levels as initial P_2O_5 increased. The mean P_2O_5 over soils and DAI increased from 92 to 117 kg ha^{-1} as P application increased from 0 to 100% RDP. Available P_2O_5 (over soils and P levels) increased significantly from 103 kg ha^{-1} at 15 DAI to 110 kg ha^{-1} at 45 DAI. The interaction of soils and DAI on P_2O_5 was significant. The combination of S1 with any level of DAI registered at par availability of P_2O_5 from 49 to 53 kg ha^{-1}. However, P_2O_5 was significantly lower than any combination of soils and DAI of S2 and S3. Within S2 and S3, P_2O_5 at any combination of DAI was significantly higher in S3 (160 to 167 kg ha^{-1}) than S2 (100 to 108 kg ha^{-1}). The combination of higher applied P with more contact periods gave higher P availability compared to lower applied P and contact periods. The combination of any DAI with 50 and 75% RDP gave similar P_2O_5 of 106 to 116 kg ha^{-1}. The interaction of soils, P level and DAI on P availability was non-significant.

At Mangalagiri, available P_2O_5 in soils increased from 55.9 to 136.1 kg ha^{-1} over P and DAI levels as initial available P_2O_5 increased from 47 to 122 kg ha^{-1}. The mean P_2O_5 of these soils over DAI increased from 81 to 110 kg ha^{-1}. The increase in available P_2O_5 due to 25% RDP was significantly higher compared to no RDP. The difference in available P_2O_5 though higher at 75% RDP (105 kg ha^{-1}) was at par with 50% RDP. Available P_2O_5 extracted at 75 and 100% RDP remained at par (105 and 110 kg ha^{-1}). The mean P_2O_5 over soils and P levels at 15 DAI was 94 kg ha^{-1} and increased to 98 kg when contact period was 30 days. At 45 days, P_2O_5 increased to 105 kg ha^{-1} and was higher than 15 DAI and at par with 30 DAI (98 kg ha^{-1}). The interaction of soil and P levels on P_2O_5 was

Table: 3
Distribution of P-fractions in soils of three locations

Soil	Initial P_2O_5 (kg ha^{-1})	P fractions (mg kg^{-1})				
		Saloid - P	Al - P	Fe - P	Red - P	Ca - P
Varni						
S1	41	9.14	24.29	22.48	18.33	88.30
S2	93	15.48	34.16	31.57	20.18	110.23
S3	151	15.88	36.44	32.86	21.40	122.54
Mean	95	13.49	31.63	28.97	19.97	107.02
Mangalagiri						
S1	47	8.81	25.60	23.80	17.87	84.64
S2	90	14.08	34.24	33.15	20.48	113.41
S3	122	14.85	35.50	35.40	24.42	129.35
Mean	86	12.58	31.78	30.78	20.92	109.13
Velugodu						
S1	51	10.11	27.94	23.53	18.22	80.84
S2	95	15.87	33.90	30.88	22.43	119.83
S3	122	16.84	36.04	36.20	23.58	131.55
Mean	89	14.27	32.63	30.20	21.40	110.74

Table: 4
Effect of P levels on soil P_2O_5 ($kg\ ha^{-1}$) due to different contact periods in different soils

Soil	0% RDP				25% RDP				50% RDP				75% RDP				100% RDP				Over-all mean
	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	
Varni	88	92	96	92	100	102	104	102	106	109	112	109	109	113	116	112	113	118	120	117	106
Mangalagiri	80	82	81	81	91	94	99	95	95	99	103	99	100	106	109	105	103	110	117	110	98
Velugodu	85	87	89	87	93	98	100	97	99	102	106	102	103	108	113	108	107	115	123	115	102

LSD	Soils (S)	P-levels (PL)	DAI	S x PL	S x DAI	PL x DAI	S x PL x DAI
Varni	6.8	8.4	6.4	14.8	11.5	13.4	NS
Mangalagiri	6.4	9.2	6.0	14.4	10.9	13.4	NS
Velugodu	7.1	13.8	8.7	15.7	12.2	19.4	NS

LSD: Least significant difference at $p < 0.05$ level, DAI: Days after incubation, RDP : Recommended dose of P_2O_5

significant. The soil with 122 kg ha^{-1} of P_2O_5 (S3) in combination with and without P application gave similar P_2O_5 like S2 with 100% RDP (102 kg ha^{-1}). Available P_2O_5 was significantly affected by soil and DAI interaction. The soil with higher P (S2 and S3) in combination with any DAI had significantly higher P_2O_5 compared to S1 and DAI combination.

At Velugodu, the P_2O_5 availability significantly increased from 62 to 136 kg ha^{-1} over P levels and DAI as P_2O_5 increased from 51 to 122 kg ha^{-1}. Available P_2O_5 over soils and DAI increased from 87 to 115 kg ha^{-1} as P application increased from 0 to 100% RDP. Available P (over soils and P levels) increased from 97 (15 DAI) to 106 (45 DAI) kg ha^{-1}. P availability was not superior compared between 15 (97 kg ha^{-1}) and 30 (102 kg ha^{-1}) DAI and 30 (102 kg ha^{-1}) and 45 (106 kg ha^{-1}) DAI. The interaction of soils and P levels was significant in influencing P_2O_5 as indicated by 75% RDP (66 kg ha^{-1}) and 100% RDP (73 kg ha^{-1}) over no P in S1. Highest available P_2O_5 of 115 kg ha^{-1} was due to S3 x 100% RDP, which was at par with S3 x 75% RDP. The interaction of soils and DAI on available P_2O_5 was significant. S1 with any level of DAI gave at par P_2O_5 of 58 to 73 kg ha^{-1}. Available P_2O_5 was significantly lower than any combination of S2 or S3 with DAI levels. Highest P_2O_5 was observed with application of 100% RDP of 45 DAI (123 kg ha^{-1}) and was at par with 50 and 75% RDP on all days of contact. Application of 0 or 25% RDP gave significantly lower P_2O_5 compared to 100% RDP with 45 DAI, except at 25% RDP + 45 DAI (100 kg ha^{-1}).

Effect of Soil P on Percent P Derived From Fertilizer (PDFF)

The effect of P on PDFF in different soils is given in Table 5. At Varni, the PDFF increased from 31.7 to 68.7% as applied P increased from 25 to 100% RDP. The increase in PDFF with each level of increment in applied P was significant. It increased significantly from 40.6 to 55.1% over P levels as contact period increased from 15 to 45 days. The interaction of soils and P levels was significant with each combination of applied P over DAI. The PDFF (82.2%) was significantly higher at 100% RDP in S1. But in S2 and S3, each combination of soil and P were significantly different and higher as applied P increased. The interaction of soil and DAI was significant. The PDFF due to 25% RDP at 45 DAI gave significantly higher PDFF of 49.5% compared to 37.3% due to 50% RDP at 15 DAI. Significantly higher PDFF of 72.4% was observed at 30 DAI due to 100% RDP compared to other combinations, except 100% RDP at 45 DAI (73.9%).

At Mangalagiri, the PDFF (%) significantly decreased from 60.4 to 40.5% as initial P_2O_5 of these soils increased from 47 to 122 kg ha^{-1}. The PDFF (over DAI) increased significantly with each level

Table: 5
Effect of P levels on Percent P derived from fertilizer due to different contact periods

Soil	25% RDP				50% RDP				75% RDP				100% RDP				Over-all mean
	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	
Varni	19.2	26.5	49.5	31.7	37.3	33.3	48.7	39.8	46.2	49.2	48.1	47.8	59.7	72.4	73.9	68.7	47.0
Mangalagiri	26.0	28.3	46.9	33.7	44.5	41.5	49.6	45.2	54.1	53.4	49.8	52.4	74.3	81.8	80.4	78.8	52.6
Velugodu	30.5	38.9	61.7	43.7	51.8	43.4	47.6	47.6	88.5	58.5	67.8	71.6	88.2	87.2	87.4	87.6	62.6
LSD		Soils (S)		P-levels (PL)		DAI		S x PL		S x DAI		PL x DAI			S x PL x DAI		
Varni		3.9		4.4		3.0		7.7		6.6		6.1			NS		
Mangalagiri		5.1		5.3		3.0		8.3		7.2		6.0			NS		
Velugodu		4.2		5.7		2.7		8.3		6.5		5.4			NS		

LSD: Least significant difference at $p < 0.05$ level, DAI: Days after incubation, RDP : Recommended dose of P_2O_5

of P from 25 to 100% RDP. This increment was significant and ranged from 33.7% at 25% RDP to 78.8% at 100% RDP. The PDFF was significantly affected by days of contact, apart from interaction of DAI and soils. The PDFF in S2 at 15 and 30 DAI was significantly lower than S1 soils at 45 DAI (66.4%). Similarly, S3 soil in combination with all DAIs had significantly lower PDFF compared to other combinations. The PDFF was affected by P levels and DAI interaction. The PDFF observed at any combination of 50 or 75 or 100% RDP at any given DAI was significantly higher than 25% RDP combination with different DAI (15 and 30).

At Velugodu, the PDFF ranged from 46.3 to 62.6%. The PDFF of soils increased from 31.5 to 80.7% as P application increased from 25 to 100% RDP. The PDFF with all levels of increment of applied P was significant. It increased from 52.1 to 55.7% as contact period increased from 15 to 45 days. The interaction of soil and P levels on PDFF was significant with each combination of applied P over DAI for any soil. The PDFF was significantly higher at 100% RDP (87.6%) in S1. The S x DAI interaction on PDFF was significant. Maximum PDFF of 66.1 and 51.7% at 45 DAI was observed with S1 and S2, respectively. The PDFF at 45 DAI in S1 was significantly higher than any combination of S2 and S3 with DAI. The PDFF of 31.5% with application of 25% RDP increased significantly with successive P levels. Highest PDFF (85.6%) was observed with 100% RDP at 30 DAI. There was a significant coefficient of determination for assessing changes in PDFF under very high soil P (R^2= 0.504), followed by high soil P (R^2=0.332), while it was low under extremely high soil P situation (R^2=0.051) as indicated in Fig. 1.

Effect of Soil P on Percent Recovery of Applied P

The effects of P levels on percent recovery of applied P based on isotopic data are given in Table 6. At Varni, the percent recovery of applied P over soil and DAI increased from 43.6 to 60.9%. The differences in percent recovery of applied P was significantly higher at 50% RDP (52.7%) compared to 25% RDP. Significant effect of DAI over P levels and soils on percent recovery of applied P was observed. The percent recovery increased significantly with DAI *i.e.* 45.6 to 52.3% (15 to 30 DAI) and 52.3 to 64.4% (30 to 45 DAI). The interaction of soils and P levels on percent recovery of P was significant. Highest recovery of 64.2% was observed due to 100% RDP in S2 and was at par with 75 and 100% RDP in S2 and S3 (59.7 and 63.5%), respectively. This was at par with 50% RDP to S1 and S2 (54.7 and 55.2%), respectively.

At Mangalagiri, the percent P recovery of 54.4% was observed in S1 and was significantly lower than S2 and S3. It was significantly affected by P levels. It increased significantly to 66.3% at 75% RDP from 44.6% observed at 25% RDP and 60.0% at 50% RDP

Table: 6
Effect of P levels on percent recovery of applied P due to different contact periods at different locations

Soil	25% RDP				50% RDP				75% RDP				100% RDP				Over-all mean
	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	15 DAI	30 DAI	45 DAI	Mean	
Varni	26.5	35.8	68.5	43.6	48.6	47.2	62.5	52.8	55.3	61.6	60.0	59.0	52.0	64.4	66.4	60.9	54.1
Mangalagiri	35.5	39.8	58.6	44.6	53.9	58.5	67.5	60.0	63.5	65.5	69.8	66.3	61.6	67.8	71.2	66.9	59.4
Velugodu	35.6	42.5	64.6	47.6	56.3	54.0	67.4	59.2	67.0	59.9	69.3	65.4	66.5	76.2	74.6	72.4	61.2

LSD	Soils (S)	P-levels (PL)	DAI	S x PL	S x DAI	PL x DAI	S x PL x DAI
Varni	5.2	3.5	2.6	10.4	9.0	5.3	NS
Mangalagiri	5.5	4.2	2.8	9.8	8.3	5.6	NS
Velugodu	2.6	1.5	1.2	5.3	4.6	2.4	5.6

LSD: Least significant difference at $p < 0.05$ level, DAI: Days after incubation, RDP : Recommended dose of P_2O_5

application. The percent P recovery remained at par with 75 and 100% RDP. It increased significantly as DAI increased from 15 to 45. The incubation effect of soils and P levels and interaction of soils and DAI on percent P recovery were significant. S3 with 45 DAI gave highest P recovery of 69.5% and was at par with 45 and 30 DAI levels in S1 and S2. Lower percent recovery of applied P was observed in S1 at 15 DAI and was at par with 30 DAI in same soil (51.5%) and S3 at 15 DAI (52.2%). The recovery of applied P was significantly affected by interaction of P and DAI. It ranged from 35.5 to 39.8% when 25% RDP was in combination with 15 and 30 DAI.

At Velugodu, the percent recovery of applied P over P and DAI levels differed significantly due to different initial soil P levels. It increased significantly from 47.6% (25% RDP) to 59.2% (50% RDP). The percent P recovery was due to 75 and 100% RDP was at par, but was higher than 25% RDP. Applied P estimated at 45 DAI was superior (69.0%) over 15 DAI (56.0%). The interaction of soils and P levels significantly affected the P recovery. Highest P recovery was observed with 100% RDP in S3 (84.5%) and was higher than any other combination. S2 + 45 DAI and S3 + 45 DAI were at par with recovery of 68.9 to 74.7%. The P recovery in S3 at 15 and 30 DAI and S2 at 45 DAI and S1 at 45 DAI were at par. 100% RDP at 45 DAI resulted in higher recovery of P. The interaction of soils, P levels and DAI on recovery of applied P was non-significant. The PDFF increased with increase in soil P under high, very high and extremely high soil fertility categories. Maximum predictability of percent P recovery existed under very high (R^2=0.424), followed by high (R^2=0.315) and extremely high soil P (R^2=0.042) category. The P recovery increased with increase in soil P under all soil fertility situations. The relationship of soil P with percent recovery of applied P in high, very high and extremely high fertility situations are depicted in Fig. 2.

An attempt was made to study the recovery of applied P employing ^{32}P isotope in selected soils. The soils fell under high, very high and extremely high categories (Muhr *et al.,* 1965). Since there is no commonality for accepted categorization like very high or high P soils, the soils employed for each location were arbitrarily categorized into 90-95 and 122-151 kg ha^{-1} as samples fell within this range. This categorization was done to throw light on P availability, PDFF and percent recovery of P as P accumulation in soils increased. The P_2O_5 of soils increased with increasing levels of P from 0 to 100% RDP. This was observed irrespective of initial P of any location. The extent of increase in P_2O_5 was from 92 to 117 kg ha^{-1} at Varni, 81 to 110 kg ha^{-1} at Mangalagiri and 87 to 115 kg ha^{-1} at Velugodu. There was an increased availability of Olsen's P_2O_5 by 27, 36 and 32% where 100% RDP was supplied to these soils compared to no RDP. Several workers studying on P availability

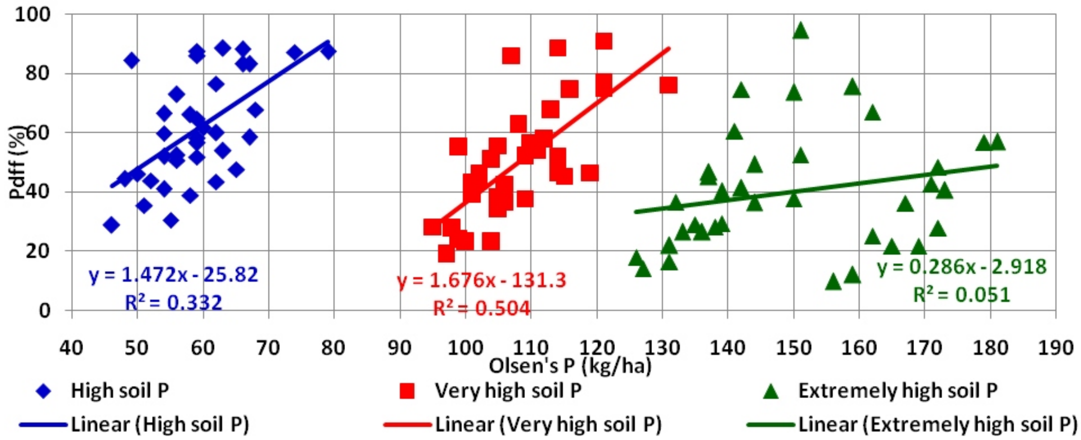

Fig. 1. Relationship between soil P and percent P derived from fertilizer in different soil fertility situations

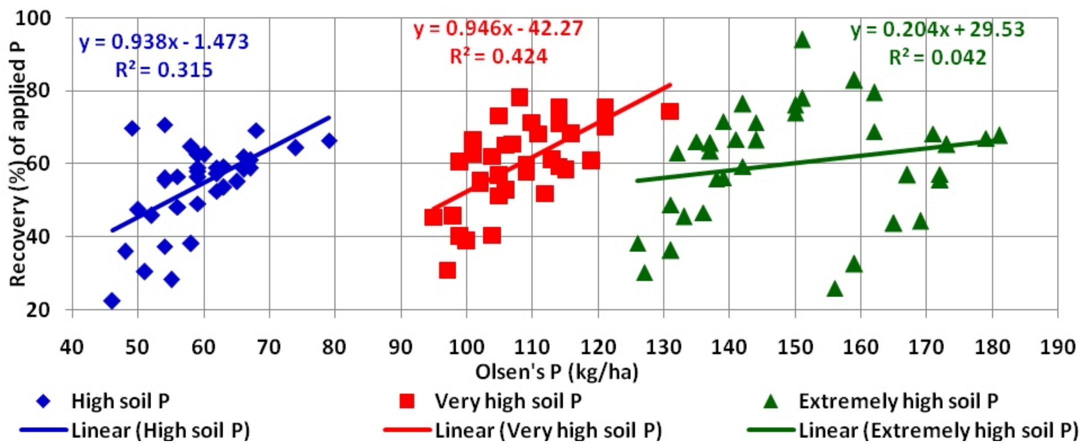

Fig. 2. Relationship between soil P and recovery of applied P in different soil fertility situations

under low and medium status reported that soil P_2O_5 increased with increased P application (Mishra *et al.,* 2012).

The available P_2O_5 due to different levels of P and after 45 DAI also varied due to varying initial soil P. The extent of increment in available P_2O_5 ha^{-1} decreased from 44 to 27% as initial soil P increased. The period through which applied P was in contact with soils also significantly affected the available P_2O_5 and increased with increased contact periods. When this aspect was looked in view of categories of P fertility, the increase in available P_2O_5 was from 51 to 59 in high fertility, 100 to 109 in very high fertility and 140 to 150 kg P_2O_5 ha^{-1} in extremely high fertility situation. Thus the extent of change in available P_2O_5 between 0 and 100% and from 15 to 45 DAI became lower as initial available P increased.

The percent PDFF increased with increase in P levels. The extent of PDFF was higher in Velugodu (31.5 to 80.7%) and less in Varni (31.7 to 68.7%). Within each soil, PDFF decreased with increasing initial P. This indicated that as initial soil P increased, P derived from fertilizer in Olsen's extractant decreased considerably. The extent of recovery ranged from 43.6 to 60.9% in Varni, 44.6 to 66.9% in Mangalagiri and 47.6 to 72.4% in Velugodu between 25 to 100% RDP. The percent P recovery was higher in Varni and Mangalagiri, when initial P_2O_5 ranged from 90 to 95 kg ha^{-1}. In Velugodu, higher initial P gave maximum percentage of P recovery. There are several reports wherein the percentage of applied P being influenced by a level of P applied or DAI, but not due to variation in initial soil P. The results presented for percent recovery of P were examined to infer the effect of different initial P fertility categories. The soils with initial high P gave mean P recovery of 54%, and as P regimes shifted to very high and extremely high fertility, it remained almost similar in the range of 59.7 to 60.4%. The available P increased at decreasing rates as P fertility increased and PDFF decreased with increasing fertility. Such a combination effect would result in variation in percent recovery with change of soil P regimes.

4. CONCLUSIONS

The survey and analysis carried out revealed that occurrence of high P soils are 98, 71 and 77%, respectively in Varni, Mangalagiri and Velugodu locations. The available P_2O_5 of these soils was 130, 97 and 95 kg ha^{-1} indicating high accumulation. When soils were grouped into high, very high and extremely high fertility categories, P-fixation capacity decreased with increasing P fertility. The saloid-P increased from 9.3 to 15.9 mg kg^{-1} when initial P_2O_5 increased from 46.3 to 131.7 kg ha^{-1}. The Al-P fraction increased from 25.9 mg kg^{-1} (high P soils) to 34.1 (for very high P soils) and 36.0 mg kg^{-1} (extremely high P soils). Such trend was observed in soils even for Fe-P, Red-P and Ca-P. The availability of applied P_2O_5 was studied employing ^{32}P isotope. The increment in P_2O_5 ha^{-1} decreased from 44 to 27% as soil P increased. The change in available P_2O_5 between 0 and 100% RDP and from 15-45 DAI became lower as initial P increased. The PDFF increased with increasing P levels. It was high in Velugodu (31.5 to 80.7%) compared to Varni (31.7 to 68.7%). With increase in DAI, PDFF increased at all locations. The recovery ranged from 43.6 to 60.9% in Varni, 44.6 to 66.9% in Mangalagiri and 47.6 to 72.4% in Velugodu. The soils with initial high P availability had P recovery of 54.0% and as P shifted to very high and extremely high categories, P recovery ranged from 60.4 to 59.7%.

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