

## Fixation of soluble forms of fertilizer phosphorus in salt affected soils of Ramanathapuram and Trichy districts and acid soil of Ariyalur district of Tamil Nadu

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### Abstract

Soluble phosphorus (P) applied through phosphatic fertilizers is quickly converted into low soluble P compounds in soil. For evaluating fixation ability of P fertilizers laboratory incubation experiments were conducted with saline, sodic and acid soils. Phosphatic fertilizers selected were single super phosphate (SSP), diammonium phosphate (DAP), monoammonium phosphate (MAP), monopotassium phosphate (MPP) and 19:19:19 N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O % (All-19). Fixation of P was computed based on the amount of P recovered after addition of P in the soil in increasing levels. At a typical P addition at 16 kg ha<sup>-1</sup> the results were compared in all soils. In saline soil, high fixation of P occurred when DAP (12.18 kg ha<sup>-1</sup>) and MPP (11.28 kg ha<sup>-1</sup>) were applied. In sodic soil, high fixation of P resulted when SSP (7.10 kg ha<sup>-1</sup>) was applied. In acid soil, high fixation of P occurred when All -19 (12.64 kg ha<sup>-1</sup>), MAP (12.40 kg ha<sup>-1</sup>), SSP (12.22 kg ha<sup>-1</sup>), and DAP (11.74 kg ha<sup>-1</sup>) were applied. With all forms of phosphatic fertilizers fixation of added P occurred to the extent of 57.9 to 79.0 per cent in acid soil, 55.0 to 70.5 per cent in saline soil and 25.5 to 44.4 per cent in sodic soil. In saline soil availability of P might be higher for SSP and All-19 compared to ammonium/ potassium phosphate fertilizers. On the other hand, MPP, MAP and All-19 may be preferably applied in sodic/ acid soils alternative to SSP or DAP for realizing higher P release in soils from added fertilizers for the benefit of crop utilization.

**Keywords:** Acid soil, P fixation, Phosphatic fertilizers, Salt affected soil, Water soluble P

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## INTRODUCTION

Phosphatic fertilizers are the greatest rescue in rendering supply of phosphorus to crops in P deficient soils, thereby help in achieving food production targets of our Nation (India). However, continuous application of P fertilizers are not efficiently utilized by crops, particularly in salt affected soils as most of the soluble P added is precipitated by metallic cations present in saline soil. This phenomenon requires utmost attention as cost of P fertilizers is high and almost all forms of P fertilizers are imported. Within a year of 2012-13 to 2013-14, All India consumption of total fertilizer nutrients declined by 3.2 per cent from 25.54 to 24.72 million metric tonnes (MMT). However, N consumption which was at 17.02 MMT, increased marginally by 1.2 per cent, while P<sub>2</sub>O<sub>5</sub> consumption which was at 5.65 MMT registered a sharp decline of 15.1 per cent during the period (Desai *et al.*, 2017).

One of the causes affecting the use of P fertilizers is a poor response of high yielding crops to applied phosphatic fertilizers, particularly in saline soils. The extent and distribution of salt-affected soils in India are around 6.7 million hectares (M ha). Out of which particularly saline soil constitutes 1.7 M ha, alkaline soil constitutes 3.8 M ha and coastal saline soil constitutes 1.2 M ha. Tamil Nadu has total salt-affected soil area of about 0.36 M ha, in that major portion is occupied by alkaline soil of around 0.35 M ha and remaining occupied by coastal saline soil of 0.1 M ha, while in inland, saline soil is not present (Mandal *et al.*, 2009). Phosphatic fertilizers are classified as water-soluble, citrate soluble, acid-soluble based on their solubility. As a straight fertilizer, single super phosphate (SSP) is conventionally used in most of the cropped lands. Nowadays, water-soluble P fertilizers are becoming popular as they are capable of releasing P into soil solution in the fastest

way. Yet, the decision on the right method of fertilizer application influences more than the selection of the right nutrient source and the right time of application.

Joshi *et al.*, (2016) studied the transformation of applied P in soil using  $^{18}\text{O}$  isotope technique and estimated precipitates of phosphate of Ca, Fe, Mn, Zn minerals formed when solution became saturated. Particularly formation of Ca phosphate was favoured by increasing solution P and Ca concentration, as well as an increase in pH (Penn and Camberato, 2019). Fang *et al.* (2019) estimated the fraction of Ca-P as 52.0 to 63.6 per cent without P inputs and indicated that Ca salts primarily determined P availability. The preferential forms of P retained in rice soils were in the order: Ca-P > Al-P > Fe-P > loosely sorbed P.

Similarly, Fe-Mn concretions and nodules are significant pedogenic components containing high amounts of Fe and Mn oxides and which has high sorption capacity for various elements. Soluble P can be trapped in the concretions/ nodules, which act as a sink for P and as a barrier to P movement from land to water bodies (Gasparatos *et al.*, 2019). In the present study different phosphatic fertilizers viz., single super phosphate (SSP), ammonium phosphates (MAP, DAP), monopotassium phosphate (MPP) and All-19 were applied in saline, sodic and acid soils of various regions of Tamil Nadu to account for fixation of P.

## MATERIALS AND METHODS

For the study, soil samples were collected from various regions of Tamil Nadu representing saline soil from Kadaladai block, Ramanathapuram district; sodic soil from ADAC&RI, Trichy district; and acid soil from Andimadam, Ariyalur. Preliminary soil analysis was performed to determine the initial characteristics of the soil.

Surface soil samples representing the 0-15 cm layer were collected from different locations of Tamil Nadu. They were air-dried, thoroughly powdered, mixed uniformly and sieved to pass through 2 mm screen. By adopting standard procedures (Jackson, 1973), the Physico-chemical and chemical properties of the soils viz., pH, EC, organic carbon, available N, P, and K, exchangeable Na, Ca, and Mg, and soluble carbonate and bicarbonate were estimated (Table 1).

Commonly used phosphatic fertilizers viz., single super phosphate (SSP), diammonium phosphate (DAP), monopotassium phosphate (MPP), mono-ammonium phosphate (MAP) and All-19 (containing 19% N, 19%  $\text{P}_2\text{O}_5$  and 19%  $\text{K}_2\text{O}$ ) were selected for the study. For the estimation of water-soluble P in fertilizers finely ground homogenous fertilizer material was taken. For evaluating the comparative quality of fertilizers, analytical grade monopotassium phosphate ( $\text{KH}_2\text{PO}_4$ ) was taken as a standard chemical source of P and used as

reference material in the study. Fertilizers were analyzed for water-soluble P by vanadomolybdo phosphoric acid yellow colour method. Based on P content estimated the primary stock solution ( $10 \text{ mg ml}^{-1}$ ) was prepared for each fertilizer source and used in the study with appropriate dilution.

**Method of laboratory incubation for fixation of P:** For each P fertilizer source, one laboratory incubation experiment was organized with a batch of containers for 16 concentrations of P in two replications. In each polythene containers (200 ml) a known weight of soil (5 g) was taken, and one ml of P solution was added. Likewise, 16 additions of P in serially increasing order of P concentration were made by taking one ml from the respective standard flask and delivering into the respective container. After the addition of soluble P, the containers were kept overnight at room temperature for incubation to allow soluble P to get reacted with mineral particles and chemical compounds that were naturally present in soils.

The selected 16 serial concentrations of solution P were in the order of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140,  $150 \mu\text{g of P ml}^{-1}$ . Soluble P for a solution was taken from different P sources viz., SSP, DAP, MPP, MAP, and All-19. These serially diluted P concentrations up to  $150 \mu\text{g of P ml}^{-1}$  in solution correspond to 0 to  $30 \text{ mg P kg}^{-1}$  of soil.

**Analysis of soil sample after incubation:** After the overnight incubation period, soil in each container was estimated for available P concentration. For which the alkaline and saline soils were extracted with 50 ml of 0.5 M  $\text{NaHCO}_3$  (Olsen, 1954) and acid soil was extracted with Bray No.1 extract then filtered through Whatman No. 3 filter paper and P was estimated by spectrophotometry method (Jackson, 1973).

**Parameters for expressing the extent of P fixation in soil:** The reaction of soluble P with mineral particles and chemical compounds in the soil after overnight incubation period was assessed by directly estimating the remaining amount of soluble P in solution. Using this result of estimation, the recovered P (Formula 1), amount of P fixed (Formula 2) and percentage of P fixed (Formula 3) were computed and interpreted for expressing the extent of P fixation in soils.

**Added soluble P recovered in extract :** After overnight incubation and fixation reaction the available P present in soil was calculated and expressed as Recovered P by the formula:

$$\text{Recovered P} = \frac{\text{P in colour solution (mg ml}^{-1}) \times \text{Extractant volume (ml)}}{\text{Aliquot of extract (ml)}} \times \frac{1000}{\text{Weight of soil (g)}} \quad \text{.....(1)}$$

Finally, the recovered P-value was adjusted by deducting available P estimated in the blank (Soil

without added P).

**Amount of fixed P in soil (mg kg<sup>-1</sup>):** Amount of fixed P was calculated by the formula:

Amount of P Fixed (mg kg<sup>-1</sup>) = [P added (mg kg<sup>-1</sup>) – Recovered P (mg kg<sup>-1</sup>)] ..... (2)

**Fixed P in soil expressed in per cent:** Phosphorus fixed in percentage was calculated by the formula:

$$P \text{ fixed (\%)} = \frac{\text{Amount of P Fixed (mg kg}^{-1}\text{)}}{\text{P added (mg kg}^{-1}\text{)}} \times 100 \text{ .....(3)}$$

The results of Recovered P and Fixed P were statistically scrutinized by analysis of variance method and tested for significance at the probability of P=0.05 by computing standard error of mean difference (SEd) and critical difference (CD) at 5% (\*) level (Panse and Sukatme, 1961).

## RESULTS AND DISCUSSION

**Initial properties of experimental soils:** The initial properties of the soils collected from different regions of Tamil Nadu representing saline, sodic and acid soils are given in Table 1. The determined EC was 11.60, 0.67 and 0.04 dS m<sup>-1</sup> in saline, sodic and acid soils respectively, wherein Na<sup>+</sup> was 0.94, 1.52 and 0.01 cmol (p<sup>+</sup>) kg<sup>-1</sup>, correspondingly Ca<sup>2+</sup> was 0.13, 0.44 and 0.05, and Mg<sup>2+</sup> was 0.15, 0.26 and 0.06 cmol (p<sup>+</sup>) kg<sup>-1</sup>. The pH of saline soil was 7.61, sodic soil was 8.89 and acid soil was 4.86. The typical characteristics of soils were noticed to be with high EC (11.60 dS m<sup>-1</sup>) of saline soil, high pH (8.89) of sodic soil and low pH (4.86) of acid soil.

**Fixation of P in saline soil:** The trend of results on Fixed P showed clear cut indication of occurrence of P fixation in soils. Addition of P in in-

creasing amount from 2 to 30 mg kg<sup>-1</sup> level increased fixation of P up to 30 mg kg<sup>-1</sup> level in saline soil (Table 2). Higher P fixation was recorded when SSP was applied in low concentration. In a similar study, salt stress causing nutritional imbalance in saline soils was found out at low concentration of P, which induced high P fixation capacity in the region of Kot Murad District Hafizabad (Mehdi *et al.*, 2018). Recovered P ranged from 0.22 to 0.56 mg kg<sup>-1</sup> at 2 to 4 mg kg<sup>-1</sup> of added P levels in the soil. Thereafter Recovered P greatly increased up to added P concentration of 30 mg kg<sup>-1</sup>. In other fertilizers P fixation was lower than SSP. Among all fertilizers, Recovered P was highest in All-19.

For MPP alone increasing P addition recorded higher range of Fixed P at 2 to 8 mg kg<sup>-1</sup>, which thereafter decreased gradually to lower values till 30 mg kg<sup>-1</sup>. SSP recorded more P fixation, when P was added from 2 to 6 mg kg<sup>-1</sup> (70.05 to 88.77 %). Among fertilizers, All-19, when added beyond 6 mg kg<sup>-1</sup>, showed a decreasing trend in Fixed P with the lowest value of 34.48 per cent at 30 mg kg<sup>-1</sup>. At a typical concentration of P addition at 8 mg kg<sup>-1</sup>, P fertilizers exhibited the ability to get fixed in saline soil in the decreasing order: DAP> MPP> MAP > SSP> All-19.

The results showed that in saline soil ammonium/potassium phosphate forms present in DAP, MPP and MAP are readily converted to low soluble forms of P when compared to monocalcium phosphates present in SSP. In addition, All-19 also showed the least fixation, possibly the form of P may be like monocalcium phosphate. Hence, it is inferred that in saline soil efficiency of P will be expected to be higher for SSP and All-19 compared to ammonium/ potassium phosphate fertiliz-

**Table 1.** Initial properties of different experimental soils.

Parameters	Soil location		
	Saline soil	Sodic soil	Acid soil
	Kadaladai block, Ramanathapuram	Field A7b, ADAC&RI, Trichy	Andimadam, Ariyalur
pH	7.61	8.89	4.86
EC dS m <sup>-1</sup>	11.60	0.67	0.04
Organic carbon (%)	0.25	0.15	0.64
Available N (kg ha <sup>-1</sup> )	295	220	230
Available P (kg ha <sup>-1</sup> )	29.8	23.2	5.5
Available K (kg ha <sup>-1</sup> )	340	325	260
Available S (kg ha <sup>-1</sup> )	15.7	6.54	2.5
Na (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	0.94	1.52	0.01
Ca (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	0.13	0.44	0.05
Mg (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	0.15	0.26	0.06
Carbonate (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	0.11	1.32	0
Bicarbonate (cmol (p <sup>+</sup> ) kg <sup>-1</sup> )	0.14	1.27	0

ers. Meena *et al.* (2019) opined that due to salt toxicity or excess amounts of soluble salts P uptake by the plants was interfered at New Delhi, India.

**Fixation of P in sodic soil:** With the addition of soluble fertilizer P in the soil in increasing concentration from 2 to 30 mg kg<sup>-1</sup>, the amount of Recovered P estimated in sodic soil also greatly increased (Table 3). In SSP, low Recovered P ranging from 1.08 to 19.62 mg kg<sup>-1</sup> was recorded, correspondingly showing higher P fixation when compared to all other fertilizers.

Recovered P was highest in MPP, which ranged from 1.54 to 28.75 mg kg<sup>-1</sup>. It meant that fertilizer P addition increased Fixed P between 2 to 8 mg kg<sup>-1</sup> thereafter decreased gradually to low values for MPP. Among the P fertilizers, SSP recorded high range of fixation ranging from 34.60 to 46.00 per cent. In addition, triple superphosphate and single superphosphate are composed of Ca phosphates such as mono-calcium phosphate. These highly soluble Ca phosphate minerals dissolve quickly and saturate the solution with Ca and P, which leads to precipitation quicker (Penn and Camberato, 2019). It was indicated that apatite P (Ca-P) was the dominant P fraction in the sodic soils at the arid and the semiarid site, and apatite was strongly positively correlated with soil pH in Coastal Cordillera of Chile (Brucker and Spohn, 2019). The lowest value of Fixed P (3.46 %) was

recorded at 28 mg kg<sup>-1</sup> level of MPP. At a typical concentration of P addition at 8 mg kg<sup>-1</sup>, P fertilizers exhibited the ability to get fixed in terms of Fixed P in sodic soil in the decreasing order: SSP> DAP> MAP> AII-19> MPP.

In contrast to the greater P fixing trend of saline/acid soil, a definite indication of the low P fixing ability of sodic soil was noticed in the present study. All forms of applied P was moderately fixed in sodic soil in proportion to applied levels of P. Furthermore, quite distinctly MPP did not undergo fixation of P at all applied levels of P. Similarly, the form of P present in AII-19 was not also fixed in sodic soil at all applied levels of P.

In a similar study, Rashid *et al.*, (2019) observed that among three different soils the highest available P (12.2 mg kg<sup>-1</sup>) was found in saline-sodic applied with P at 400 mg kg<sup>-1</sup> than salt-affected and neutral soil. These results are indicative of a positive relationship between soil sodicity and soluble P status of soil in Pakistan.

**Fixation of P in acid soil:** The addition of soluble P in increasing levels also increased Recovered P in acid soil correspondingly (Table 4). Among fertilizers SSP showed higher P fixation by recording the lowest values of Recovered P from 0.08 to 13.96 mg kg<sup>-1</sup>. Low fixation of P occurred in other fertilizers, and it was lowest in MPP, which recorded Recovered P ranging from 0.28 to 17.86 mg kg<sup>-1</sup>.

**Table 2.** Recovered P and Fixed P estimated in saline soil of Kadaladai block, Ramanathapuram district of Tamil Nadu.

P added (mg kg <sup>-1</sup> )	Recovered P (mg kg <sup>-1</sup> )					Fixed P (%)				
	MPP	SSP	DAP	AII-19	MAP	MPP	SSP	DAP	AII-19	MAP
2	0.79	0.22	0.34	0.79	0.56	60.69	88.77	83.15	60.69	71.92
4	1.35	0.56	0.79	1.68	1.24	66.30	85.96	80.34	57.88	69.11
6	1.91	1.80	1.24	2.58	1.91	68.18	70.05	79.41	56.94	68.18
8	2.36	3.48	1.91	3.59	3.37	70.52	56.48	76.13	55.07	57.88
10	3.93	4.94	2.58	4.72	4.83	60.69	50.58	74.17	52.83	51.70
12	4.83	5.95	3.26	5.84	5.62	59.75	50.39	72.86	51.33	53.20
14	5.73	6.96	4.94	6.85	6.51	59.08	50.26	64.70	51.06	53.47
16	7.53	7.64	5.73	7.75	7.19	52.97	52.26	64.20	51.56	55.07
18	8.09	7.97	7.64	9.32	7.41	55.07	55.70	57.57	48.21	58.82
20	9.21	9.32	8.20	10.56	7.86	53.95	53.39	59.00	47.21	60.69
22	10.45	10.67	9.55	11.79	9.32	52.52	51.50	56.60	46.39	57.62
24	12.58	11.91	10.56	13.25	10.00	47.58	50.39	56.01	44.78	58.35
26	14.71	13.48	11.57	14.83	11.23	43.41	48.16	55.50	42.98	56.80
28	15.72	14.83	12.47	17.86	12.80	43.84	47.05	55.47	36.22	54.27
30	17.52	16.40	13.59	19.66	16.17	41.59	45.34	54.70	34.48	46.09
SEd	0.27	0.27	0.25	0.37	0.22	1.59	1.46	1.14	1.72	1.22
CD	0.47	0.47	0.44	0.66	0.39	2.79	2.56	2.00	3.02	2.13

Critical difference (CD) expressed at P=0.05

**Table 3.** Recovered P and fraction of P fixed in sodic soil of ADAC&RI, Trichy district of Tamil Nadu.

P added (mg kg <sup>-1</sup> )	Recovered P (mg kg <sup>-1</sup> )					Fixed P (%)				
	MPP	SSP	DAP	All-19	MAP	MPP	SSP	DAP	All-19	MAP
2	1.54	1.08	1.20	1.31	1.25	23.00	46.00	40.00	34.50	37.50
4	3.12	2.21	2.43	2.66	2.58	22.00	44.75	39.25	33.50	35.50
6	4.78	3.33	3.78	4.00	3.91	20.33	44.50	37.00	33.33	34.83
8	5.96	4.45	5.13	5.46	5.35	25.50	44.38	35.88	31.75	33.13
10	8.12	5.69	6.93	7.26	7.15	18.80	43.10	30.70	27.40	28.50
12	10.34	6.93	8.39	8.83	8.72	13.83	42.25	30.08	26.42	27.33
14	12.64	8.16	9.85	10.71	10.29	9.71	41.71	29.64	23.50	26.50
16	14.38	9.73	11.64	13.74	12.09	10.13	39.19	27.25	14.13	24.44
18	16.13	10.63	13.10	15.04	13.78	10.39	40.94	27.22	16.44	23.44
20	18.88	11.87	14.68	17.12	17.64	5.60	40.65	26.60	14.40	11.80
22	20.48	13.55	16.70	19.21	19.76	6.91	38.41	24.09	12.68	10.18
24	22.67	15.35	18.27	21.24	22.03	5.54	36.04	23.88	11.50	8.21
26	24.67	16.70	20.07	22.97	23.46	5.12	35.77	22.81	11.65	9.77
28	27.03	18.16	21.64	25.76	26.03	3.46	35.14	22.71	8.00	7.04
30	28.75	19.62	23.55	26.86	27.21	4.17	34.60	21.50	10.47	9.30
SEd	0.53	0.43	0.28	0.52	0.39	3.23	2.25	2.20	2.96	2.13
CD	0.93	0.76	0.49	0.91	0.68	5.66	3.94	3.85	5.18	3.73

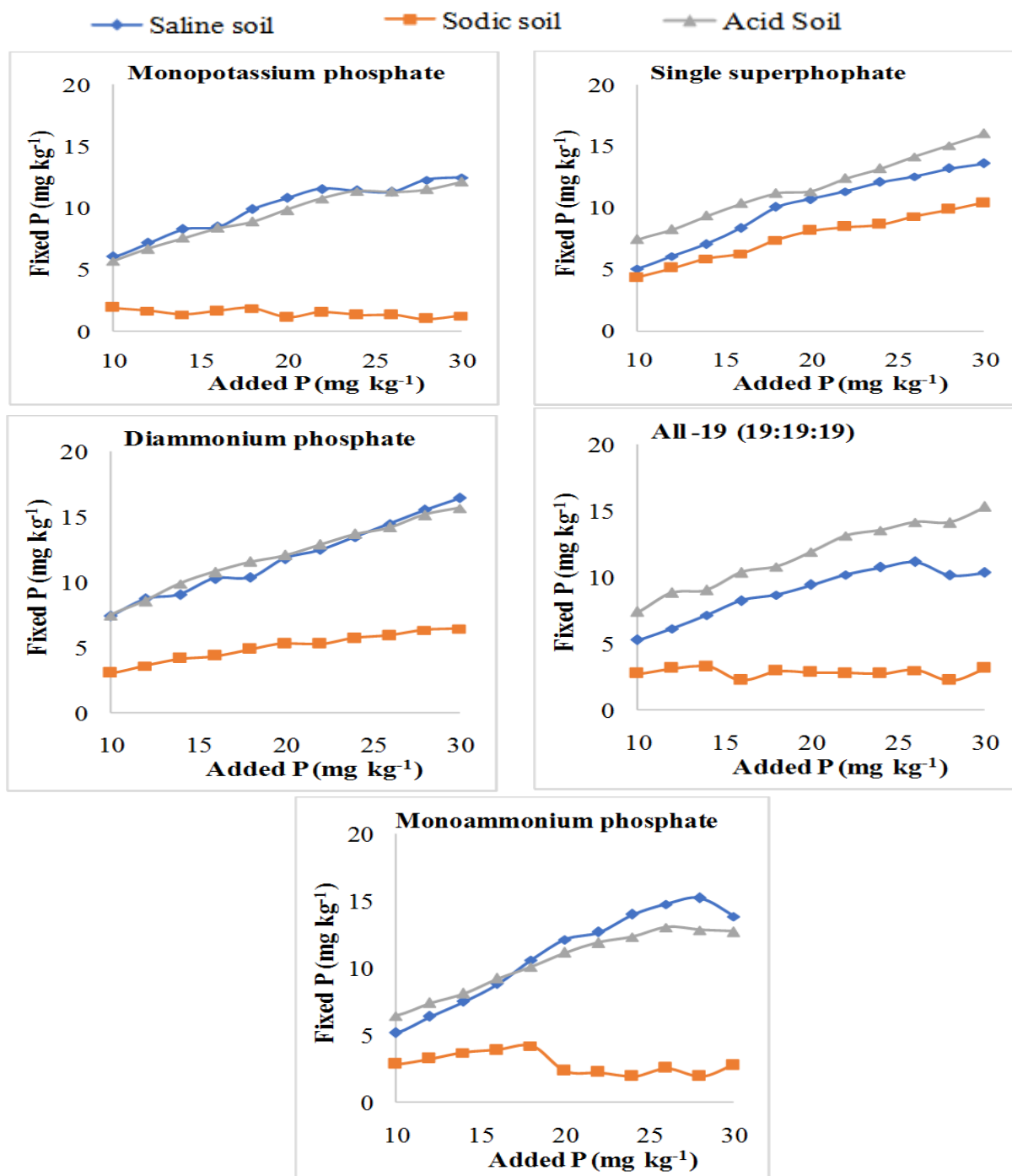
Critical difference (CD) expressed at P=0.05

**Table 4.** Recovered P and fraction of P fixed in acid soil of Andimadam, Ariyalur district of Tamil Nadu.

P added (mg kg <sup>-1</sup> )	Recovered P (mg kg <sup>-1</sup> )					Fixed P (%)				
	MPP	SSP	DAP	All-19	MAP	MPP	SSP	DAP	All-19	MAP
2	0.28	0.08	0.17	0.11	0.22	86.00	96.00	91.50	94.50	89.00
4	0.96	0.73	0.67	0.87	0.79	76.00	81.75	83.25	78.25	80.25
6	2.01	1.26	1.46	1.24	1.35	66.50	79.00	75.67	79.33	77.50
8	3.37	1.89	2.13	1.68	1.80	57.88	76.38	73.38	79.00	77.50
10	4.31	2.58	2.52	2.58	3.54	56.90	74.20	74.80	74.20	64.60
12	5.31	3.75	3.45	3.14	4.61	55.75	68.75	71.25	73.83	61.58
14	6.45	4.68	4.10	4.94	5.87	53.93	66.57	70.71	64.71	58.07
16	7.64	5.67	5.21	5.62	6.78	52.25	64.56	67.44	64.88	57.63
18	9.13	6.84	6.43	7.19	7.91	49.28	62.00	64.28	60.06	56.06
20	10.17	8.67	7.94	8.09	8.84	49.15	56.65	60.30	59.55	55.80
22	11.23	9.64	9.12	8.87	10.10	48.95	56.18	58.55	59.68	54.09
24	12.64	10.84	10.32	10.45	11.67	47.33	54.83	57.00	56.46	51.38
26	14.67	11.84	11.80	11.86	12.97	43.58	54.46	54.62	54.38	50.12
28	16.50	12.94	12.86	13.87	15.16	41.07	53.79	54.07	50.46	45.86
30	17.86	13.96	14.34	14.68	17.30	40.47	53.47	52.20	51.07	42.33
SEd	0.20	0.21	0.28	0.27	0.18	1.14	0.98	1.29	1.14	1.06
CD	0.36	0.37	0.49	0.47	0.31	2.01	1.72	2.26	2.00	1.87

Critical difference (CD) expressed at P=0.05





**Fig. 1.** Magnitude of fixation of phosphorus in saline soil (Ramanathapuram district), sodic soil (Trichy district) and acid soil (Ariyalur district) of Tamil Nadu.

The calculated values of Fixed P indicated the extent of P fixation occurring in acid soil distinctly. Among the P fertilizers, SSP recorded high range of fixation ranging from 53.47 to 96.00 per cent. The lowest value of Fixed P (40.47 %) was recorded at 28 mg kg<sup>-1</sup> of added P for MPP. At a typical concentration of P addition at 8 mg kg<sup>-1</sup>, P fertilizers exhibited the ability to get fixed in terms of

Fixed P in acid soil in the decreasing order: All-19> MAP> SSP> DAP> MPP. These results are in line with the study of Eduah *et al.*, (2019) who estimated P sorption capacity of the two acid soils and expressed that P fixation in acid soils ranged from 296 - 395 mg kg<sup>-1</sup>, which was more than two folds of neutral soil (105 mg kg<sup>-1</sup>) at Ghana. The trend of P fixation observed in the present study at different levels of applied P was closely

similar for ammonium/ potassium phosphates in saline soil and acid soil. In the case of SSP and All-19 fixation was low in acid soil and moderate in saline soil. This trend of results implies that MPP, MAP and All-19 may be preferably applied in acid soils alternative to SSP or DAP to realize enhanced P availability to crops.

For instance, rock phosphate is the only direct source of P for acid soil which leads to the effective release of P than in neutral and calcareous soils (Johnston et al., 2014). Based on anion exchange reactions it was found that phosphate adsorption occurring onto variable charged minerals such as Al and Fe oxides/ hydroxides and 1:1 minerals were more favoured by low pH (Penn and Camberato, 2019). Dominantly soil iron can act as a critical variable at the locations of acidity for mediating the impact of precipitation on total P concentration in China (Tang et al., 2019; Zhang et al., 2020).

**Fixation of P in different soils:** Among the soils studied, in saline and acid soils high P fixation occurred for DAP and a moderate range of P fixation occurred for other fertilizers. In sodic soil, high P fixation occurred for SSP and a moderate range of fixation occurred in other fertilizers (Fig. 1). With the addition of soluble fertilizer P in increasing concentration, fixation of P also increased. By accounting for fixation of added P on per hectare (ha) basis, the result of the study can be extrapolated. In a ha furrow slice surface soil (15 cm depth) it is calculable that 2 million kg soil would be present at optimum bulk density.

Based on soil weight of one hectare, the saline soil typical P addition of 16 kg ha<sup>-1</sup> could cause high fixation of P when DAP (12.18 kg ha<sup>-1</sup>) and MPP (11.28 kg ha<sup>-1</sup>) are used, moderate fixation when MAP (9.26 kg ha<sup>-1</sup>), SSP (9.04 kg ha<sup>-1</sup>) are used and low fixation when All-19 (8.82 kg ha<sup>-1</sup>) is used. In sodic soil at typical P addition of 16 kg ha<sup>-1</sup> could cause high fixation of P when SSP (7.10 kg ha<sup>-1</sup>) is used, moderate fixation when DAP (5.74 kg ha<sup>-1</sup>), MAP (5.30 kg ha<sup>-1</sup>), All -19 (5.08 kg ha<sup>-1</sup>) and MPP (4.08 kg ha<sup>-1</sup>) are used. In acid soil at typical P addition of 16 kg ha<sup>-1</sup> could cause high fixation of P when All-19 (12.64 kg ha<sup>-1</sup>) is used, moderate fixation when MAP (12.40 kg ha<sup>-1</sup>), SSP (12.22 kg ha<sup>-1</sup>) DAP (11.74 kg ha<sup>-1</sup>) MPP (9.26 kg ha<sup>-1</sup>) are used. With all forms of phosphatic fertilizers, out of typical P addition of 16 kg ha<sup>-1</sup>, fixation of P occurred to the extent of 57.9 to 79.0 per cent in acid soil, 55.0 to 70.5 per cent in saline soil and 25.5 to 44.4 per cent in sodic soil.

The results on the extent of P fixation (Fig. 1) showed that the increased addition of fertilizer P decreased the amount of Fixed P in soils. Based on the studies, soil acidity causes the adverse effect on P concentration, because the soil has more free Al ions than the H<sup>+</sup> ions in soil solution. In this situation, metal ions are capable of adsorb-

ing P, causing very low ionic concentration in soil solution due to P-metal ions precipitation (Selim, 2018). Alike the present study, Rashid et al., (2019) conducted studies with neutral, salt-affected and saline-sodic soil and concluded that all three soils behaved differently for P distribution among various fractions with different levels of P application in Pakistan.

## Conclusion

Among the phosphatic fertilizers evaluated in the present study, the addition of P through single super phosphate was preferably fixed in the greatest amount in acid soil compared to saline/ sodic soil. In sodic soil fixation of P recorded was least for all P fertilizers. Based on comparative P fixing ability of soils, it could be inferred that in saline soil availability of P might be higher for SSP and All-19 compared to ammonium/ potassium phosphate fertilizers. On the other hand, MPP, MAP and All-19 may be preferably applied in sodic/ acid soils alternative to SSP or DAP. Interpretations and findings emanated from the study may have a practical lookup for applying an entire dose of P fertilizer as a basal dressing with respect to P fixation trends in soils with chemical problems. It may imply that in saline and acid soils, split application of fertilizer P may increase P use efficiency. There is also a need to devise new methods of inhibiting the chemical interaction of the soluble P forms with cations of high P fixing soils.

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