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Status of available phosphorus, forms and distribution of phosphorus in soil under major cropping systems of Nellore district, A.P

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Abstract
An investigation was undertaken during 2018-19 in Southern zone of A.P. to study the Status of available phosphorus and forms of Phosphorus in soil under major cropping systems of Nellore district. The Ca-P was observed to be the predominant P fraction under all major cropping systems could be attributed to high $CaCO_3$ content. The highest mean values for saloid-P (16.67 mg kg^{-1}), total-P (538.21 mg kg^{-1}) and other forms of P (342.07 mg kg^{-1}) were recorded in groundnut-paddy cropping system and Fe- P (68.77 mg kg^{-1}) and Al-P (61.85 mg kg^{-1}) were highest in paddy-paddy cropping system, whereas available P_2O_5 (166.82 kg ha^{-1}) and Ca-P (173.15 mg kg^{-1}) were highest in groundnut-paddy and fallow-bengalgram systems, respectively. pH showed positive and significant relation with total-P (r= 0.507**) and other forms of P (r= 0.573**) where as free $CaCO_3$ showed positive and significant correlation with Ca-P (r= 0.432*) in calcareous soils of S.P.S.R. Nellore district. Available P_2O_5 showed positive and significant correlation with saloid-P (r= 0.456*), Al-P (r= 0.765**) and Fe-P (r= 0.559**), saloid-P showed significant and positive correlation with total-P (r= 0.477*) and other forms of P (r= 0.510**). Al-P showed positive and significant correlation with Fe-P (r= 0.885**). Similarly, Ca-P showed positive and significant relation with total-P (r= 0.418*).

Keywords: Calcareous soils, P fraction, cropping systems

Introduction
Phosphorus is the tenth most abundant element in the earth's crust and its average content is nearly 0.12 per cent. In lithosphere, it always occurs in the pentavalent oxidation state. Phosphorus is an essential element for plant growth. Therefore, maintainance of an adequate amount of soil phosphorus through application of inorganic and/ or organic phosphorus is critical for the sustainability of cropping systems.
Knowledge of amount of each fraction and their relationship with soil characteristics is very useful in assessing phosphorus nutrition of plants. Since various P fractions and their contribution to available phosphorus provide useful information in assessing the available P status of soils and various forms of soil phosphorus have different solubility under varying soil condition. Available P content increases with the application of P. The increase in available P is a function of certain physical and chemical soil properties, such as clay, organic carbon, Fe, Al and calcium carbonate contents. Marked variation in the different forms of inorganic P is a function of genetic differences among soils (Chang and Jackson, 1958) [4].

Materials and methods
Five soil samples from each cropping system (Paddy-Paddy, Fallow-Paddy, Fallow-Blackgram, Groundnut-Paddy, and Fallow-Bengalgram) at 0-15cm depth from farmer's field were collected from calcareous soils of S.P.S.R Nellore district of southern zone of A.P. The soils were mildly to moderately alkaline in reaction, non-saline and below the critical limits, free lime content indicates that these soils were calcareous. These soil samples were analysed for status of available P_2O_5 (Olsen-P) and different P fractions (Sal-P, Al-P, Fe-P, Ca-P, total-P and other forms of P). The available phosphorus was extracted by using Olsen's extractant (0.5 M $NaHCO_3$ of pH 8.5) as described by Olsen *et al.* (1954) [13] and the phosphorus content in the extract was determined by Murphy and Riley (1962) [12] method using ascorbic acid as the reducing agent using spectrophotometer.
The inorganic phosphorus fractions *viz.*, saloid-P, Fe-P, Al-P and Ca-P were estimated by following the sequential extraction procedure as given by Kovar and Pierzynski (2009) [8]. Total phosphorus in the soils was determined by perchloric acid digestion method as described

by Jackson (1973) [7]. The other P forms were computed by deducting the estimated forms viz., saloid-P, Al-P, Fe-P and Ca-P from total-P. The other forms include org-P, RS-P, occl-P, etc.

Results and discussion

Physico-chemical properties of soil

pH

In S.P.S.R. Nellore district where soils were calcareous, the pH of surface soils varied from 7.31 in paddy-paddy cropping system to 8.31 in fallow-blackgram cropping system with a mean value of 7.42 and 8.18, respectively (Table 1). The mean pH in different cropping systems were in the order of fallow-blackgram system (8.18) followed by fallow-bengalgram system (7.93), groundnut-paddy system (7.70), fallow-paddy system (7.54) and paddy-paddy system (7.42).

From the Table 4 it was observed that pH showed positive significant relation with total-P (r= 0.507**) and other forms of P (r= 0.573**) and negative but significant correlation with Al-P (r= -0.611**) and Fe-P (r= -0.703**). Similar results were reported by Watham *et al.* (2018) [20] with Fe-P and Al-P and Majumdar *et al.* (2004) [11] with total-P and Org-P.

Electrical conductivity (EC)

The electrical conductivity measured in the calcareous soils of S.P.S.R. Nellore district was non-saline and below the critical limits, and the results are as follows. In S.P.S.R. Nellore where soils were calcareous, the EC of surface soils varied from 0.009 dSm^{-1} in fallow-blackgram cropping system to 0.108 dSm^{-1} in fallow-paddy cropping sequence with a mean value of 0.012 and 0.072 dSm^{-1}, respectively (Table 1). The highest EC mean values were obtained in fallow-paddy system (0.072 dSm^{-1}) followed by paddy-paddy system (0.03 dSm^{-1}), groundnut-paddy system (0.028 dSm^{-1}), fallow-bengalgram system (0.025 dSm^{-1}) and fallow-blackgram system (0.012 dSm^{-1}).

From the Table 4 it was observed that EC showed non-significant and positive correlation with Fe-P. Similar results were reported by Devra *et al.* (2014) [6] in calcareous soils of western plain of Rajasthan.

Free $CaCO_3$

In S.P.S.R. Nellore district where soils were calcareous, the free $CaCO_3$ of surface soils varied from 6% in fallow-paddy system to 19% in fallow-bengalgram system with a mean value of 6.3% and 15.2%, respectively (Table 1). The highest free $CaCO_3$ mean values were obtained in fallow-bengalgram system (15.2%) followed by paddy-paddy system (10.8%), groundnut-paddy system (8.8%), fallow-blackgram system (7%) and fallow-paddy system (6.3%). The highest free $CaCO_3$ (15.2%) under fallow-bengalgram system in calcareous soils of S.P.S.R. Nellore district might be due to low or little dissolution effect, since bengalgram is grown under residual soil moisture conditions in rabi season compared to all other cropping systems.

From the Table 4 it was observed that free $CaCO_3$ showed positively significantly correlated with Ca-P (r= 0.432*). Similar reports were reported in calcareous soils by Devra *et al.* (2014) [6] and Bhavsar *et al.* (2018) [2].

Available P_2O_5

The data on available phosphorus in soil under different cropping systems is presented in table presented in Table 2. The available P_2O_5 of surface soils varied from 32.84 kg ha^{-1} in fallow-paddy system to 206.28 kg ha^{-1} in groundnut-paddy system with a mean value of 35.65 kg ha^{-1} and 166.82 kg ha^{-1}, respectively. The highest available P_2O_5 mean values were obtained in groundnut-paddy system (166.82 kg ha^{-1}) followed by paddy-paddy system (136.05 kg ha^{-1}), fallow-bengalgram system (49.8 kg ha^{-1}), fallow-blackgram system (44.77 kg ha^{-1}) and fallow-paddy system (35.65 kg ha^{-1}).

The available P_2O_5 was very high in groundnut-paddy and paddy-paddy cropping systems might be due to continuous and excess addition of manures and fertilizers in both the seasons which solubilise the native inorganic P compounds thus increase the P availability. The low availability in other systems might be during fallow period the available P gets converted to unavailable fixed P forms.

From the Table 4 it was observed that, available P_2O_5 showed positive and significant correlation with saloid-P (r= 0.456*), Al-P (r= 0.765**) and Fe-P (r= 0.559**). It may be indicating that these fractions mainly contributing towards available-P pool of the soil. Similar results were reported by Laxminarayana (2007) [9] and Anjali and Dhananjaya (2017) [1].

Inorganic P fractions

Saloid-P

The data on saloid-P in soil under different cropping systems is presented in Table 3. The saloid-P of surface soils varied from 3.5 mg kg^{-1} in fallow-bengalgram system to 22.26 mg kg^{-1} in groundnut-paddy system with a mean value of 4.75 mg kg^{-1} and 16.67 mg kg^{-1}, respectively. The highest saloid-P mean values were obtained in groundnut-paddy system (16.67 mg kg^{-1}) followed by fallow-blackgram system (15.02 mg kg^{-1}), paddy-paddy system (6.18 mg kg^{-1}), fallow-paddy (5.13 mg kg^{-1}), fallow-bengalgram system (4.75 mg kg^{-1}).

The lowest saloid-P content in paddy-paddy and fallow-paddy systems might be due to high uptake and utilization of P compared to other systems. However, the lowest saloid-P in fallow-bengalgram system is due to high fixation and low utilization by bengalgram crop during *rabi* season.

Higher values obtained in groundnut-paddy system might be due to high dose of application of P from manures and fertilizers. Similar results were reported by Viswanatha and Doddamani (1991) [19] and Sowjanya *et al.* (2017) [18].

From the Table 4, it was observed that, saloid-P showed significant and positive correlation with total-P (r= 0.477*) and other forms of P (r= 0.510**) and positive and non-significant correlation with Al-P. Similar results reported by Bhavsar *et al.* (2018) [2] and Majumdar *et al.* (2004) [11], Devra *et al.* (2014) [6] with total-P and Org-P. Similar results were reported by Anjali and Dhananjaya (2017) [1] with total-P.

Al-P

The data on Al-P in soil under different cropping systems is presented in Table 3. The Al-P of surface soils varied from 13.68 mg kg^{-1} in fallow-bengalgram system to 75.03 mg kg^{-1} in paddy-paddy cropping sequence with a mean value of 21.75 mg kg^{-1} and 61.85 mg kg^{-1}, respectively. The highest mean values were obtained in paddy-paddy (61.85 mg kg^{-1}) followed by groundnut-paddy system (46.34 mg kg^{-1}), fallow-paddy system (32.26 mg kg^{-1}), fallow-blackgram system (27.86 mg kg^{-1}) and fallow-bengalgram system (21.75 mg kg^{-1}).

The low Al-P content in fallow-bengalgram, fallow-blackgram and fallow-paddy systems might be due to low utilization by respective crops. The highest Al-P under paddy-paddy system might be due to favourable reduced conditions.

From the Table 4, it was observed that Al-P showed positive and significant correlation with Fe-P (r= 0.885**) and negative significantly correlated with other forms of P (r= -0.452*). Similar results were reported by Chandrakala *et al.* (2017) [3] based on phosphorus fertility gradients with Fe-P and Org-P.

Fe-P
The data on Fe-P in soil under different cropping systems is presented in Table 3. The Fe-P of surface soils varied from 12.94 mg kg^{-1} in fallow-bengalgram system to 80.61 mg kg^{-1} in paddy-paddy cropping sequence with a mean value of 27.31 mg kg^{-1} and 68.77 mg kg^{-1}, respectively. The highest Fe-P mean values were obtained in paddy-paddy system (68.77 mg kg^{-1}) followed by fallow-paddy system (38.79 mg kg^{-1}), groundnut-paddy system (38.40 mg kg^{-1}), fallow-bengalgram system (27.31 mg kg^{-1}) and fallow-blackgram system (20.14 mg kg^{-1}).
Higher values of Fe-P in paddy-paddy, fallow-paddy and groundnut-paddy systems might be attributed to deep prolonged weathering due to longer wet period as a result of lower topographic situation which might have brought about the transformation of Ca-P to Fe-P. Similar findings were observed by Singh *et al*. (2003) [17] and Sowjanya *et al.* (2017) [18]. The low Fe-P recorded under fallow-blackgram and fallow-bengalgram systems might be due to low addition of p fertilizers to pulse crops and high fixation.
It is observed that Fe-P (Table 4) showed positive and significant correlation with Al-P (r= 0.885**) and negative significantly correlated with other forms P (r= -0.654**). Similar results were reported by Chandrakala *et al.* (2017) [3] based on phosphorus fertility gradients with Fe-P and Org-P.

Ca-P
The data on Ca-P in soil under different cropping systems is presented in Table 3. The Ca-P of surface soils varied from 38.62 mg kg^{-1} in fallow-paddy system to 323.62 mg kg^{-1} in fallow-bengalgram system with a mean value of 51.75 mg kg^{-1} and 173.15 mg kg^{-1}, respectively. The highest Ca-P mean values were obtained in fallow-bengalgram system (173.15 mg kg^{-1}) followed by paddy-paddy system (103.47 mg kg^{-1}), groundnut-paddy system (94.73 mg kg^{-1}), fallow-blackgram system (81.09 mg kg^{-1}) and fallow-paddy system (51.75 mg kg^{-1}).
Highest values of Ca-P obtained in fallow- bengalgram system might be due to high amount of $CaCO_3$ and calcareous nature of soil and may be attributed to the presence of higher amounts of soluble P as observed by Saha *et al.* (2013) [16]. The higher Ca-P under paddy-paddy, groundnut-paddy and fallow-blackgram systems might be due to higher application of P fertilizers. The lowest values were recorded in fallow-paddy cropping system might be due to low $CaCO_3$ content and conversation of Ca-P to other P forms (Fe-P).
From the Table 4, it was observed that Ca-P showed positive and significant relation with total-P (r= 0.418*). Similar results were reported by Majumdar *et al.* (2004) [11], Lungmuana *et al.* (2012) [10], Devra *et al.* (2014) [6], Anjali and Dhananjaya (2017) [1] and Bhavsar *et al.* (2018) [2].

Total-P
The data on total-P in soil under different cropping systems is presented in Table 3. The total-P of surface soils varied from 269.23 mg kg^{-1} in paddy-paddy system to 662.67 mg kg^{-1} in groundnut-paddy system with a mean value of 329.88 mg kg^{-1} and 538.21 mg kg^{-1}, respectively. The highest total-P mean values were obtained in groundnut-paddy system (538.21 mg kg^{-1}) followed by fallow-bengalgram system (525.43 mg kg^{-1}), fallow-blackgram system (460.27 mg kg^{-1}), fallow-paddy system (386.02 mg kg^{-1}) and paddy-paddy system (329.88).
Under groundnut-paddy system the high soluble P resulted in high total-P. The highest content of total-P in surface layer in fallow-bengalgram system might be due to low utilization of applied P by bengalgram crop. Under fallow-paddy and paddy-paddy systems the total-P is a result of high external addition of P fertilizers and high utilization by crops.
From the Table 4, it was observed that total-P showed significant and positive correlation with saloid-P (r= 0.477*) and Ca-P (r= 0.418*). The close association of Ca-P with total-P is because of the dominance of Ca-P in soils. Similar results were reported by Deobhatia and Deopal (1988) [5], Paramasivan and Udaysoorian (1991) [14] and Patgiri and Dutta (1993) [15]. Similar results were reported by Majumdar *et al.* (2004) [11], Lungmuana *et al.* (2012) [10], Devra *et al.* (2014) [6] and Anjali and Dhananjaya (2017) [1].

Other forms of P
The data on other forms of P in soil under different cropping systems is presented in Table 3. The other forms of P of surface soils varied from 45.67 mg kg^{-1} in paddy-paddy system to 456.93 mg kg^{-1} in groundnut-paddy system with a mean value of 89.61 mg kg^{-1} and 342.07 mg kg^{-1}, respectively. The highest other forms of P mean values were obtained in groundnut-paddy system (342.07 mg kg^{-1}) followed by fallow-blackgram system (316.16 mg kg^{-1}), fallow-bengalgram system (298.46 mg kg^{-1}), fallow-paddy system (258.09 mg kg^{-1}) and paddy-paddy system (89.61 mg kg^{-1}).

Conclusion
In calcareous soils of S.P.S.R. Nellore district, Ca-P was the predominant P fraction in all the cropping systems due to high $CaCO_3$ content. The highest mean values for saloid P (16.67 mg kg-1), total-P (538.21 mg kg-1) and other forms of P (342.07 mg kg-1) were recorded in groundnut-paddy cropping system and Fe- P (68.77 mg kg-1) and Al-P (61.85 mg kg-1) were highest in paddy-paddy cropping system, whereas available P_2O_5 (166.82 kg ha-1) and Ca-P (173.15 mg kg-1) were highest in groundnut-paddy and fallow-bengalgram systems, respectively.

The sequential distribution of different forms of P under major cropping systems in S.P.S.R. Nellore district followed the order:
1. Paddy-Paddy: Ca-P > Fe-P > Al-P > Sal-P
2. Fallow-Paddy: Ca-P > Fe-P > Al-P > Sal-P
3. Fallow-Blackgram: Ca-P > Al-P > Fe-P > Sal-P
4. Groundnut-Paddy: Ca-P > Al-P > Fe-P > Sal-P
5. Fallow-Bengalgram: Ca-P > Fe-P > Al-P > Sal-P

Table 1: Physico-chemical properties of calcareous soils under different cropping systems in S.P.S.R. Nellore district

S. No.	Cropping system	pH	EC (dSm^{-1})	$CaCO_3$%
1	Paddy-Paddy	7.31-7.60 (7.42)	0.013-0.039 (0.028)	9-12.5 (10.8)
2	Fallow-Paddy	7.41-7.74 (7.54)	0.01-0.108 (0.072)	6-6.5 (6.3)
3	Fallow-Blackgram	8.08-8.31 (8.18)	0.009-0.014 (0.012)	6.5-9.5 (7)
4	Groundnut-Paddy	7.54-7.84 (7.70)	0.016-0.038 (0.028)	5-14 (8.8)
5	Fallow-Bengalgram	7.82-8.11 (7.93)	0.006-0.037 (0.025)	11-19 (15.2)

Note: Figures in parentheses indicate the mean value.

Table 1: Status of available P_2O_5 (kg ha^{-1}) under major cropping systems in calcareous soils of S.P.S.R Nellore district

S. No.	Cropping system	Available P_2O_5
1	Paddy-Paddy	75.91-195.73 (136.05)
2	Fallow-Paddy	32.84-40.01 (35.65)
3	Fallow-Blackgram	33.29-61.04 (44.77)
4	Groundnut-Paddy	117.24-206.28 (166.82)
5	Fallow-Bengalgram	41.69-72.22 (49.8)

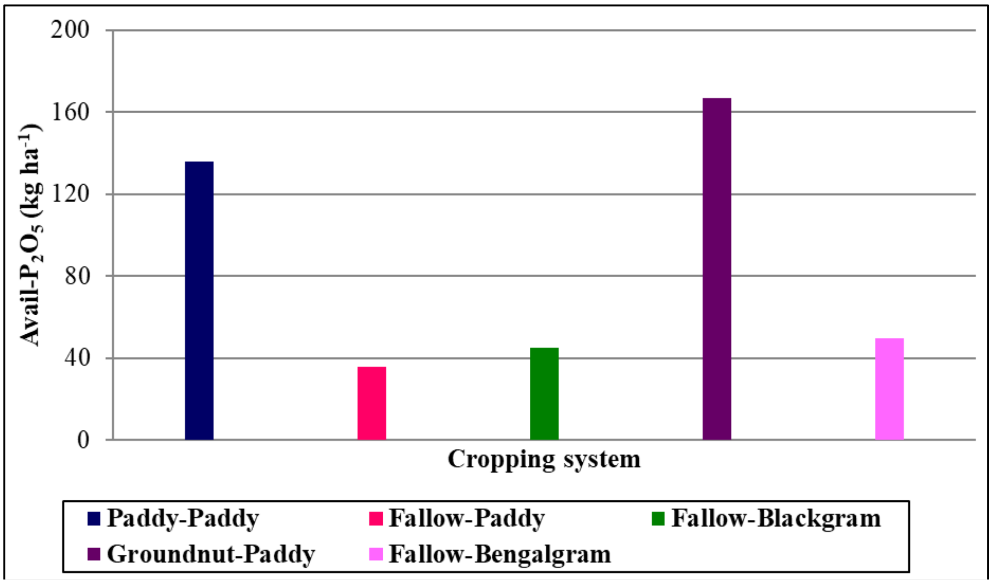

Fig 1: Status of available P_2O_5 under different cropping systems in calcareous soils of S.P.S.R. Nellore district

Table 2: Distribution of different forms of P (mg kg^{-1}) under major cropping systems in calcareous soils of S.P.S.R Nellore district

S. No.	Cropping system	Sal-P	Al-P	Fe-P	Ca-P	Total-P	Other P forms
1	Paddy-Paddy	3.62-7.82 (6.18)	54.63-75.03 (61.85)	61.89-80.61 (68.77)	79.67-120.02 (103.47)	269.23-405.21 (329.88)	45.67-134.35 (89.61)
2	Fallow-Paddy	3.65-6.37 (5.13)	26.87-44.5 (32.26)	26.08-48.16 (38.79)	38.62-72.9 (51.75)	315.68-493.19 (386.02)	185.97-321.25 (258.09)
3	Fallow-Blackgram	12.74-17.78 (15.02)	21.54-33.09 (27.86)	15.26-26.18 (20.14)	72.9-87.08 (81.09)	326.6-588.69 (460.27)	200.8-426.93 (316.16)
4	Groundnut-Paddy	10.64-22.26 (16.67)	42.08-49.79 (46.34)	31.96-41.59 (38.40)	90.93-98.04 (94.73)	481.04-662.67 (538.21)	302.37-456.93 (342.07)
5	Fallow-Bengalgram	3.5-5.61 (4.75)	13.68-26.33 (21.75)	12.94-40.9 (27.31)	116.91-323.62 (173.15)	441.32-578.85 (525.43)	182.73-400.7 (298.46)

Note: Figures in parentheses indicate the mean value.

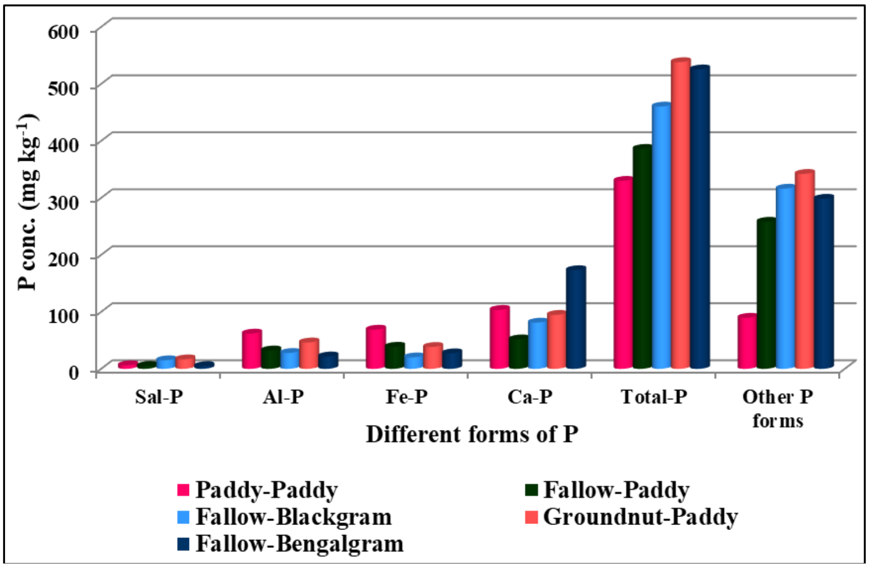

Fig 2: Forms of phosphorus under different cropping systems in calcareous soils of S.P.S.R. Nellore district

Table 3: Correlation coefficient between soil properties and forms of phosphorus (mg kg^{-1}) under different cropping systems in calcareous soils of S.P.S.R. Nellore district

	PH	EC	$CaCO_3$%	Avail- P_2O_5	Sal-P	Al-P	Fe-P	Ca-P	Total-P	Other P forms
Avail- P_2O_5	-0.429*	-0.197	0.121	1						
Sal-P	0.370	-0.396	-0.202	0.456*	1					
Al-P	-0.611**	-0.045	-0.092	0.765**	0.122	1				
Fe-P	-0.703**	0.133	0.018	0.559**	-0.239	0.885**	1			
Ca-P	0.215	-0.258	0.432*	0.118	-0.148	-0.075	0.080	1		
Total-P	0.507**	-0.305	0.217	0.174	0.477*	-0.201	-0.345	0.418*	1	
Other P forms	0.573**	-0.167	0.020	-0.111	0.510**	-0.452*	-0.654**	-0.077	0.834**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

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