Int.J.Curr.Microbiol.App.Sci (2017) *6*(11): 281-294

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 11 (2017) pp. 281-294**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.611.033

Phosphorus Fractions- Keys to Soil based P Management

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Keywords

Fertility gradients, Finger millet – maize cropping system, Graded levels of P, Soil phosphorus fractions.

Article Info

Accepted:
04 September 2017
Available Online:
10 November 2017

A B S T R A C T

Red soils (*Alfisols*) of Karnataka are low in total and available phosphorus (P). When soluble P sources are added, undergo transformation into unavailable forms with time. Native P compounds, some being highly insoluble are unavailable for plant uptake. Thus, knowing the changes in P fractions in different soils is much important for P recommendation. The objective of the study was to find out the fate of the applied phosphorus in soils of different P fertility in a finger millet-maize cropping system. An experiment with creation of five P fertility gradient strips (Very low, Low, Medium, High and Very high) in one and the same field followed by response of finger millet and maize crops to graded levels of P was undertaken at UAS, Bangalore. Soil P fractions were determined in a soil after the harvest of maize in a finger millet- maize cropping system. There was an increase in total-P, organic-P, reductant soluble-P, occluded-P and calcium-P fractions with the increased gradient strips from very low to very high applied with levels of P. Whereas, saloid-P, aluminium-P and iron-P are the slowly and plant available labile-P forms which were decreased as the P fertility gradients and dose of P addition increased. There was a direct relationship with addition, fixation and distribution of P fractions. Hence, continuous P fertilization can be restricted in soils of high and very high initial P status as the PUE was 20-40 per cent only in general leads to build-up and transformation in to non-labile P forms.

Introduction

The total phosphorus level of soil is not only low but also P compounds are mostly unavailable for plant uptake. The concentrations of phosphorus in the soil solution (intensity) and capacity of the soil to supply phosphorus to the soil solution are important factors affecting P availability. As the basic raw material rock phosphate available in the country is only 10 per cent of the total requirement hence, fertilizer industry in India is not self sufficient in meeting the requirement of P therefore, depends on imports for the balance of 90 per cent (Chandrakala, 2014).

Phosphorus (P) dynamics in soil and maintenance of its adequate supply are important for sustainability (Song *et al.,* 2007). The application of P to each crop in a rotation and low recovery of added P has been found to result in its significant build up in soils (Brar *et al.,* 2004). Application of fertilizer phosphorus is essential for raising the available P content in soils in order to meet the crop requirements at different stages of growth. The availability of soil P to plants depends on the replenishment of labile P from other P fractions. Nwoke *et al.,* (2004) observed that the changes in different inorganic-P fractions in soils under a wide range of management conditions. The extent of P depletion ranged from 33 to 129 per cent over a period of 11 years (Nambiar and Ghosh, 1984; Tandon, 1987).

Knowing the initial soil test value and recovery of added phosphates, it will be possible to work out the amount of fertilizer phosphorus needed to build-up the soil phosphate to a given critical limit. Soil based P management relies on maintenance of adequate soil P fertility and replenishment of P nutrient removed by harvested grain. However, there is a need to know the effect of P addition and distribution in soils of different P status for sustained P management and improved PUE in the region. In the light of the above facts, a field experiment was undertaken involving gradient creation followed by response of finger millet (*Eleusine coracana* L.) - maize (*Zea mays* L.), are the major crops cultivated in Karnataka among millets and cereals, respectively.

The objective of the investigation is to assess the availability of phosphorus and their different fractions in soils of different phosphorus fertility gradients applied with graded levels of P to finger millet- maize cropping system.

Materials and Methods

The field experiment comprised of two stages. Fertility gradient creation was the preparatory step as per the procedure of Ramamoorthy *et al.,* (1967) followed by finger millet-maize cropping system in the subsequent seasons.

Experimental site

The experiment was conducted during 2009-2010 at D-16 Block, Zonal Agricultural Research Station (ZARS), GKVK, UAS, Bengaluru which is located in Eastern Dry Zone of Karnataka at latitude of $12^0$58' N and longitude of $75^0$35' E with an altitude of 930 m above mean sea level.

Soil characteristics of experiment site

Surface soil (0-15 cm) was analyzed for physical and chemical properties and also determined phosphorus fractions by adopting standard procedures. Soils are reddish brown laterite derived from gneiss under subtropical semiarid climate. The soil of experimental site was red sandy clay loam in texture, acidic in reaction, low in available nitrogen (203.84 kg ha^{-1}) and phosphorus (18.42 kg ha^{-1}) and medium in available potassium (147.12 kg ha^{-1}) content (Table 1).

Experimental details

Creation of fertility gradient strips

Five equal strips (45 × 8.2 m^2) were created in one and the same field and named very low (VL), low (L), medium (M), high (H) and very high (VH) gradient strips as P_0, P_1, P_2, P_3 and P_4, respectively. Graded doses of phosphorus *viz*. 0, 20, 40, 80 and 120 kg ha^{-1} was applied through fertilizer and organics 50 per cent each so as to achieve Very low (<15 kg P_2O_5 ha^{-1}), Low (16-30 kg P_2O_5 ha^{-1}), Medium (31- 45 kg P_2O_5 ha^{-1}), High (46 - 60 kg P_2O_5 ha^{-1}) and Very high (> 60 kg P_2O_5 ha^{-1}) P levels in the respective strips. Exhaustive crop fodder maize (South African tall) was grown provided with recommended doses of nitrogen (100 kg ha^{-1}), phosphorus (50 kg P_2O_5 ha^{-1}) and potassium (25 kg K_2O ha^{-1}) and green fodder was harvested at 60 days after sowing. Soils in each strip analyzed for available nutrients status. Available P_2O_5 content obtained in P_0, P_1, P_2, P_3 and P_4, was 14.82, 27.37, 38.76, 52.25, 80.72 kg ha^{-1}, respectively.

Studies on the changes in soil P and different P fractions

After harvest of exhaustive crop, each strip was divided in to three replications and further each replication was sub divided in to seven treatment plots of equal size. Finger millet (GPU-28) was grown (spacing: 20 x 10 cm) during summer followed by maize (Nithyashree Hybrid) was grown (spacing: 60 x 30 cm) during *kharif* 2011 by imposing treatments in a factorial RCBD design. Treatment details as follows; T_1: Absolute control; T_2: Package of Practice (NPK+FYM); T_3: 100 % Rec. N, P &K only (no FYM); T_4: 75 % Rec. P + rec. dose of N&K (no FYM); T_5: 75 % Rec. P + Rec. dose of N&K only+ Rec. FYM; T_6: 125 % Rec. P + Rec. dose of N&K (no FYM); T_7: 125 % Rec. P + Rec. dose of N&K + Rec. FYM. Recommended dose of fertilizer for finger millet was 50- 40- 25 kg N- P_2O_5- K_2O ha^{-1} whereas for maize 100-50-25 kg N-P_2O_5-K_2O ha^{-1} was given. Recommended dose of FYM given was 7.5 t ha^{-1}.

Soil sampling and analysis

After the harvest of maize in a finger millet-maize cropping system, The representative soil samples were collected at 0-15 cm depth from all the plots separately, which were analyzed for available P and their fractions as per the standard procedures as follows.

Total phosphorus was estimated by vanado-molybdo phosphoric yellow colour method (Hesse, 1971). Organic phosphorus was determined by deducting the sum of total inorganic phosphorus from total phosphorus as suggested by Mehta *et al.,* (1954). The available phosphorus was extracted using Bray's No.1 extractant for the soils having pH less than 6.5 and Olsen's extractant for the soils having pH 6.5 and above. The extracted phosphorus was estimated by chloro-stannous reduced molybdo-phosphoric blue colour method (Jackson, 1973).

The method outlined by Peterson and Corey (1966) was followed to fractionate soil inorganic phosphorus. Saloid-P was estimated by molybdo-sulphuric acid reagent, using stannous chloride as reductant. Aluminium phosphorus (Al-P) determined by chloro-molybdic-boric acid reagent and chloro-stannous reductant using the soil residue left after saloid-P estimation. The soil sediment from Al-P estimation, was then used to determine iron phosphorus (Fe-P) by chloro-molybdic-boric acid reagent and chloro-stannous reductant.

Reductant soluble phosphorus (R-P) estimation was done by taking the soil residue from Fe-P, using molybdate-sulphuric acid reagent with stannous chloride as reductant. The soil residue left out in the estimation of R-P was determined for Occluded phosphorus (Occl-P) by chloro-molybdic-boric acid reagent with chloro-stannous reductant. The soil residue left over after extraction of occluded phosphorus, was used to determine calcium phosphorus (Ca-P) by chloro-molybdic-boric acid reagent with chloro-stannous reductant.

Data computation

The experimental data were analyzed using ANOVA (One-Way). Critical differences among treatments were estimated at 5 % probability level of significance. Correlation studies were made and the values of correlation coefficient (r) were calculated and tested for their significance (Panse and Sukhatme, 1967).

Results and Discussion

Data presented in Table 2 to 6 depicted changes in phosphorus fractions after harvest of maize in a finger millet-maize cropping system which showed significant differences among mean values of P gradients, treatments and their interaction.

Fertility gradients effect

There was an increase in, total-P (Table 2), organic-P (Table 3), RS-P (Table 5), occluded-P (Table 6) and Ca-P (Table 6) fractions with the increased fertility gradient strips from very low to very high strip. This might be due to application of P in the increasing dose in order to create fertility gradients. Enrichment of the total and available P (Fig. 1) status as the PUE (Table 8) by the crops was 20-40 per cent only in general. There was a positive correlation exists (Table 7a) between T-P and Org-P, RS-P, Occl-P and Ca-P fractions (0.997*, 0.999*, 0.974* and 0.992*, respectively). There were also recorded increased Org-P, RS-P, Occl-P and Ca-P fractions with the increased T-P content of soil.

Unlike T-P, org-P, RS-P, occl-P and Ca-P fractions, S-P (Table 3), Al-P (Table 4) and Fe-P (Table 4) fractions were decreased as the P fertility gradients increased. This may be due to transformation of these fractions in to non-labile forms of P. The Al-P and Fe-P fractions were higher in very low and low gradient strips, might be due to acidic soil pH resulting in transformation of added P in to Al-P and Fe-P fractions. Majumdhar *et al.,* (2007) observed that the contribution of Org-P to T-P was 48.90 to 53.70 per cent. They also noticed significant increase in S-P, Al-P, Fe-P and Ca-P but decrease in reductant-soluble and occluded-P fractions. Setia and Sharma (2007) observed that application of P @ 17.50 or 35 kg P ha^{-1} increased all the forms of P in 22 years of maize-wheat cycles. The relative abundance of P fractions was in the order of saloid-P < Fe-P < Al-P < Ca-P. Jakasaniya and Trivedi (2004) also noticed that the increase in S-P, Al-P, Fe-P and Ca-P fractions with increase in rate of P addition in different soils. Org-P showed a buildup due to sorghum cropping in all soils.

Treatments effect

Application of graded levels of P with gradient strips had direct relationship with quantity and distribution of P fractions. The quantity of P fractions was higher as the rate of P application was higher. Application of 125 % rec. P + rec. N&K + rec. FYM to very high gradient strip recorded higher T-P and Org-P followed by nutrients application as per package of practice and 125 % rec. P + rec. N&K. Labile-P forms (S-P, Al-P and Fe-P) were higher when P was added along with manure may be due to lesser fixation of P and chelating action of manures which keeps the P in solution there by reducing the transformation of labile P in to non-labile P forms. Non labile pool was enriched when P was added at higher rate without manure application. Anil kumar (2013) reported that application of manures recorded significantly higher available P over control.

Among the fractions Fe-P, Ca-P and organic P fractions in soil remained unaltered while Saloid-P and Al-P fractions were increased in comparison to their initial concentration. Sukhvir Kaur (2015) reported that the application of integrated fertilizers recorded significantly higher Sa-P concentration compared to inorganic only.

Fig.1 AvP_2O_5 in soils of different P fertility strips as influenced by graded levels of applied P

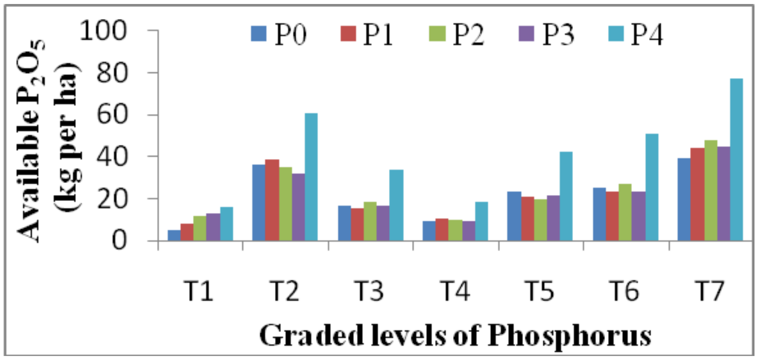

Table.1 Initial soil properties of experimental site

Parameters	Values
Coarse sand (%)	33.2
Fine sand (%)	36.3
Silt (%)	7.5
Clay (%)	23.0
Textural Class	Sandy Clay loam
CEC [c mol (p^+) kg^{-1}]	11.10
pH (1:2.5)	5.55
EC (dS m^{-1})	0.26
Organic Carbon (%)	0.45
Available N (kg ha^{-1})	203.84
Available P_2O_5 (kg ha^{-1})	18.4
Available K_2O (kg ha^{-1})	147.1
Exchangeable Ca [c mol (p+) kg^{-1}]	6.75
Exchangeable Mg [c mol (p+) kg^{-1}]	3.60
Avail. S (mg kg^{-1})	10.82
DTPA-Fe (mg kg^{-1})	55.8
DTPA-Mn (mg kg^{-1})	59.5
DTPA-Cu (mg kg^{-1})	2.21
DTPA-Zn (mg kg^{-1})	2.35
B (mg kg^{-1})	0.54
Phosphorus fractions	
Total P (mg kg^{-1})	1115.0
Saloid–P(mg kg^{-1})	48.70
Al-P (mg kg^{-1})	70.52
Fe-P (mg kg^{-1})	135.66
Reductant soluble-P (mg kg^{-1})	146.85
Occluded-P (mg kg^{-1})	11.07
Calcium-P (mg kg^{-1})	10.53
Organic-P (mg kg^{-1})	691.67

Table.2 Changes in total soil phosphorus fraction (Total P) after harvest of maize

P levels/Treatments	Total- P(mg kg^{-1})					
	P_0	**P_1**	**P_2**	**P_3**	**P_4**	**Mean**
T_1	726.33	1086.50	1113.33	1331.67	1517.92	**1155.15**
T_2	1288.67	1543.67	1676.67	1724.67	1810.83	**1608.90**
T_3	1033.33	1220.83	1337.67	1430.42	1563.08	**1317.07**
T_4	959.00	1198.17	1247.75	1436.25	1501.58	**1268.55**
T_5	1121.33	1308.75	1403.75	1538.00	1757.58	**1425.88**
T_6	1075.33	1431.00	1533.67	1694.17	1797.07	**1506.25**
T_7	1381.00	1619.00	1701.33	1890.33	1989.75	**1716.28**
Mean	**1083.57**	**1343.99**	**1430.60**	**1577.93**	**1705.40**	**1428.30**
	F	***S.Em±***		**CD *(p=0.05)***		**CV**
P	S	37.06		104.58		11.89
T	S	43.85		123.74		
P x T	NS	-		-		

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Table.3 Changes in organic and saloid soil phosphorus fractions (mg kg^{-1}) after harvest of maize

P levels/ Treatments	Org-P						S- P					
	P_0	**P_1**	**P_2**	**P_3**	**P_4**	**Mean**	**P_0**	**P_1**	**P_2**	**P_3**	**P_4**	**Mean**
T_1	425.91	646.00	674.71	889.70	1066.52	**740.57**	47.98	53.81	50.73	39.27	36.07	**45.57**
T_2	691.64	924.07	1105.90	1132.47	1197.97	**1010.41**	84.07	89.25	54.03	44.60	43.67	**63.12**
T_3	418.03	614.30	758.43	864.18	971.38	**725.26**	64.82	72.49	49.73	40.23	34.00	**52.25**
T_4	415.16	614.73	725.73	921.25	1065.17	**748.41**	64.14	77.59	48.43	41.09	36.28	**53.51**
T_5	593.89	722.71	879.12	1020.05	1230.28	**889.21**	70.73	81.77	55.61	52.89	47.96	**61.79**
T_6	466.37	792.52	933.56	1089.97	1160.29	**888.54**	50.20	66.47	38.95	39.55	37.93	**46.62**
T_7	706.63	969.11	1141.60	1318.74	1417.07	**1110.63**	85.84	90.52	45.74	42.21	35.73	**60.01**
Mean	**531.09**	**754.78**	**888.43**	**1033.77**	**1158.38**	**873.29**	**66.83**	**75.99**	**49.03**	**42.83**	**38.81**	**54.70**
	F	***S.Em±***		**CD *(p=0.05)***		**CV**	**F**	***S.Em±***		**CD *(p=0.05)***		**CV**
P	S	12.74		35.96		6.68	S	1.92		5.42		16.11
T	S	15.08		42.55			S	2.27		6.42		
P x T	S	33.72		95.15			S	5.08		14.35		

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Table.4 Changes in aluminium phosphorus and iron phosphorus fractions (mg kg^{-1}) of soil after harvest of maize

P levels/ Treatments	Al- P						Fe- P					
	P_0	P_1	P_2	P_3	P_4	Mean	P_0	P_1	P_2	P_3	P_4	Mean
T_1	57.55	89.92	77.21	72.45	68.90	**73.20**	48.06	85.05	79.08	68.45	63.29	**68.79**
T_2	100.96	104.77	86.98	85.27	87.17	**93.03**	101.07	90.97	84.26	90.65	90.78	**91.55**
T_3	97.66	88.74	75.08	64.67	56.29	**76.49**	102.92	77.03	67.49	42.21	68.90	**71.71**
T_4	93.78	94.48	72.21	70.67	69.24	**80.07**	87.24	93.07	61.26	50.38	51.32	**68.65**
T_5	101.41	96.80	82.24	74.73	71.51	**85.34**	91.27	107.20	77.81	67.00	63.36	**81.33**
T_6	85.52	83.95	65.41	63.45	61.92	**72.05**	85.18	75.28	69.78	44.87	61.88	**67.40**
T_7	119.85	99.09	77.92	75.88	70.96	**88.74**	123.00	97.58	60.00	56.52	48.85	**77.19**
Mean	**93.82**	**93.96**	**76.72**	**72.44**	**69.43**	**81.28**	**91.25**	**89.45**	**71.38**	**60.01**	**64.05**	**75.23**
	F	***S.Em±***		**CD *(p=0.05)***		**CV**	**F**	***S.Em±***		**CD *(p=0.05)***		**CV**
P	S	1.72		4.86		9.72	S	3.38		9.52		20.56
T	S	2.04		5.75			S	3.99		11.27		
P x T	S	4.56		12.86			S	8.93		25.20		

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Table.5 Changes in reductant soluble phosphorus fraction (RS-P) of soil after harvest of maize

P levels/ Treatments	RS- P (mg kg^{-1})					
	P_0	P_1	P_2	P_3	P_4	Mean
T_1	130.18	183.03	196.17	219.13	230.17	**191.74**
T_2	275.10	291.77	297.13	314.17	327.13	**301.06**
T_3	307.13	317.13	326.10	337.20	345.10	**326.53**
T_4	266.17	275.17	287.03	295.23	308.07	**286.33**
T_5	235.20	266.90	268.23	277.10	289.20	**267.33**
T_6	335.23	348.30	353.07	365.07	376.23	**355.58**
T_7	304.03	314.27	323.10	338.13	346.93	**325.29**
Mean	**264.72**	**285.22**	**292.98**	**306.58**	**317.55**	**293.41**
	F	***S.Em±***		**CD *(p=0.05)***		**CV**
P	S	2.62		7.39		4.11
T	S	3.10		8.74		
P x T	S	6.92		19.54		

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Table.6 Changes in occluded and calcium phosphorus fractions (mg kg^{-1}) of soil after harvest of maize

P levels/ Treatments	Occluded – P						Ca- P					
	P_0	P_1	P_2	P_3	P_4	Mean	P_0	P_1	P_2	P_3	P_4	Mean
T_1	11.54	19.92	25.33	29.47	35.82	**24.42**	5.03	8.77	10.10	13.20	17.17	**10.85**
T_2	20.63	25.67	29.10	35.24	37.93	**29.72**	15.07	17.17	19.27	22.27	26.23	**20.00**
T_3	25.73	28.64	33.27	50.42	53.26	**38.26**	17.03	22.50	27.57	31.51	34.17	**26.55**
T_4	20.42	23.90	29.73	32.44	40.89	**29.47**	12.10	19.23	23.37	24.93	30.55	**22.04**
T_5	18.73	20.30	25.53	29.13	35.06	**25.75**	10.10	13.07	15.20	17.17	20.27	**15.16**
T_6	29.80	36.28	39.27	54.50	58.21	**43.61**	23.03	28.21	33.63	36.80	40.60	**32.45**
T_7	21.77	26.17	31.27	32.68	41.03	**30.58**	20.07	22.27	23.00	26.17	29.17	**24.13**
Mean	**21.23**	**25.84**	**30.50**	**37.70**	**43.17**	**31.69**	**14.63**	**18.74**	**21.73**	**24.58**	**28.31**	**21.60**
	F	***S.Em±***		**CD *(p=0.05)***		**CV**	**F**	***S.Em±***		**CD *(p=0.05)***		**CV**
P	S	0.77		2.16		11.07	S	0.48		1.35		10.16
T	S	0.91		2.56			S	0.57		1.60		
P x T	S	2.03		5.72			S	1.27		3.57		

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Table.7a Correlation among soil phosphorous fractions as influenced by phosphorous fertility gradients

Correlation	TP	Or-P	S-P	Al-P	Fe-P	RS-P	Occl-P	Ca-P
TP	1							
Or-P	0.997**	1						
S-P	-0.801	-0.844	1					
Al-P	-0.893*	-0.925*	0.980**	1				
Fe-P	-0.885*	0-.914*	0.950*	0.979**	1			
RS-P	0.999**	0.998**	-0.815	-0.902*	-0.894*	1		
Occl-P	0.974**	0.983**	-0.880*	-0.932*	-0.914*	0.982**	1	
Ca-P	0.992**	0.996**	-0.855	-0.926*	-0.901*	0.995**	0.991**	1

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

Table.7b Correlation among soil phosphorous fractions as influenced by graded levels of phosphorus

Correlation	TP	Or-P	S-P	Al-P	Fe-P	RS-P	Occl-P	Ca-P
TP	1							
Or-P	0.954**	1						
S-P	0.634	0.653	1					
Al-P	0.682	0.738	0.959**	1				
Fe-P	0.583	0.625	0.874*	0.898**	1			
RS-P	0.643	0.394	0.176	0.124	0.045	1		
Occl-P	0.231	-0.029	-0.367	-0.41	-0.346	0.826*	1	
Ca-P	0.426	0.171	-0.156	-0.185	-0.255	0.942**	0.939**	1

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

Table.8 PUEP (Phosphorus Use Efficiency Per cent) by finger millet and maize

P levels/ Treatments	Finger millet						Maize					
	P_0	P_1	P_2	P_3	P_4	Mean	P_0	P_1	P_2	P_3	P_4	Mean
T_1	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	**0.00**
T_2	31.24	28.25	27.36	24.11	15.85	**25.36**	38.40	38.89	39.13	42.85	38.00	**39.45**
T_3	31.56	30.95	26.51	24.09	15.41	**25.70**	36.93	42.88	40.16	44.86	38.29	**40.62**
T_4	33.74	30.00	27.79	24.18	17.49	**26.64**	37.55	44.30	43.61	48.20	44.35	**43.60**
T_5	31.75	28.12	28.00	24.68	16.18	**25.75**	36.93	42.36	43.92	45.08	40.43	**41.74**
T_6	36.55	29.86	27.40	23.65	15.77	**26.65**	38.99	44.36	42.29	43.53	34.55	**40.74**
T_7	31.48	29.56	26.55	25.97	15.44	**25.80**	36.83	39.54	39.37	39.30	35.59	**38.13**
Mean	**32.72**	**29.46**	**27.27**	**24.44**	**16.02**	**25.98**	**37.61**	**42.05**	**41.41**	**43.97**	**38.53**	**40.72**

T_1: Absolute control
T_2: Package of Practice (rec. NPK+FYM)
T_3: 100 per cent rec. N, P & K (no FYM)
T_4: 75 per cent rec. P + rec. N&K (no FYM)
T_5: 75 per cent rec. P + rec. N&K+ rec. FYM
T_6: 125 per cent rec. P + rec. N&K (no FYM)
T_7: 125 per cent rec. P + rec. N&K + rec. FYM

P_0: Very low Phosphorus fertility strip
P_1: Low Phosphorus fertility strip
P_2: Medium Phosphorus fertility strip
P_3: High Phosphorus fertility strip
P_4: Very high Phosphorus fertility strip

Irrespective of P gradient strips, the treatments have influenced correlations between P fractions (Table 7b). T-P and Org-P were correlated positively with all the P fractions except Occl-P which was negatively correlated with Org-P. However, S-P, Al-P and Fe-P were positively correlated with each other but were negatively related with Occl-P and Ca-P. There was a significant and positive correlation noticed between RS-P, Occl-P and Ca-P. Further, Occl-P and Ca-P were negatively related with S-P, Al-P and Fe-P.

Interaction effect

Very low gradient strip with absolute control and their interaction effect showed lower content of all the P fractions which could be due to utilization of native soil P as well as lack of external nutrient inputs. Murthy *et al.*, (2002) observed increased phosphorus fractions with the increased rate of P application. Singaram and Kothandaraman (1993) also reported the application of P at the rate of 0, 30, 60 and 90 kg ha^{-1} significantly increased the S-P, Al-P, Fe-P, RS-P and Ca-P as compared to initial content.

There was a positive balance of available P in soil when fertilized with P and higher buidup of phosphorus was observed at the harvest. The recommended fertilizer P rates used were high enough to maintain the P balance or even to buildup soil P. In most LTFE experiments confirming the residual effects of fertilizer P (Dobermann *et al.*, 1996). More and Agale (1993) observed the P balance at 0 and 25 kg P_2O_5 ha^{-1} rate was negative. However, 50 and 75 kg ha^{-1} resulted in buildup of available P in soil. Dobermann *et al.*, (1996) noticed average negative P balances of -7.0 to -8.0 kg P ha^{-1} per season for -P treatments in LTFE experiments, whereas +P treatments had an average net P gain of 3.7 to 4.9 kg ha^{-1} per season. Pawar and Jadhav (1995) also observed positive P balance under groundnut-sorghum sequence, whereas balance of these nutrient was negative under fallow-sorghum sequences.

The build-up of P in gradient strips with levels of P application in a cropping system as well as the increased total-P, organic-P, reductant soluble-P, occluded-P and Ca-P fractions as the soil phosphorus fertility increased. And the reverse trend was noticed for saloid-P, Al-P and Fe-P fractions. There was a direct relationship with addition, fixation and distribution of P fractions. Therefore, continuous P fertilization can be restricted in soils of high and very high P fertility gradient strips.

Acknowledgments

I would like to thank chairman and members of advisory committee, staff's of Dept. of SS&AC, UAS, Bangalore, NBSS&LUP and ICAR and my beloved family members and friends. Thankful to ICAR, New Delhi for granting SRF and RKVY, Govt. of Karnataka for providing financial assistance for conducting research.

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How to cite this article:

Chandrakala, M., C.A. Srinivasamurthy, V.R.R. Parama, S. Bhaskar, Sanjeev Kumar and Naveen, D.V. 2017. Phosphorus Fractions- Keys to Soil based P Management. *Int.J.Curr.Microbiol.App.Sci.* 6(11): 281-294. doi: https://doi.org/10.20546/ijcmas.2017.611.033