Int.J.Curr.Microbiol.App.Sci (2017) *6*(11): 310-324

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 11 (2017) pp. 310-324**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.611.035

Phosphorus Status in Soils of Eastern Dry Zone, Karnataka, India

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Keywords

Available soil phosphorus, Eastern Dry zone Karnataka, P Fractions.

Article Info

Accepted:
04 September 2017
Available Online:
10 November 2017

A B S T R A C T

Phosphorus (P) deficiency is second to nitrogen (N) and its deficiency is widespread. Soil based site specific P recommendation for sustainable crop productivity mainly relies on status, and availability of phosphorus. Representative soil samples (250) from different agro-ecological regions of Eastern Dry Zone (EDZ) of Karnataka were analysed for P status and randomly collected samples were analysed for P fractions. Results revealed that, AvP (Available phosphorus) ranged 12.74 to 94.70; 11.21 to 49.55; 10.70 to 98.32 and 10.22 to 64.05 kg ha^{-1} in Bangalore Rural, Tumkur, Kolar and Chikkaballapura districts, respectively. Among P fractions, total-P (range: 1218.90-3383.08 mg kg^{-1}), organic-P (range: 624.95-3461.85 mg kg^{-1}), reductant soluble-P (range: 132.56-364.55 mg kg^{-1}), occluded-P (range: 7.38-49.69 mg kg^{-1}) and Ca-P (range: 6.21-38.76 mg kg^{-1}) content increased as the P fertility of soil increased and decreasing trend was recorded for Saloid-P (range: 38.31-63.23 mg kg^{-1}), Al-P (range: 61.49-164.31 mg kg^{-1}) and Fe-P (range: 35.23-109.87 mg kg^{-1}) fractions. Total account of phosphorus is necessary tool for soil based P recommendation under both irrigated and rainfed agriculture.

Introduction

Phosphorus has been the subject of intensive research because of its complex nature. The complexity arises because of three main factors. First, the total phosphorus level of soil is low. Second, the native phosphorus compounds are mostly unavailable for plant uptake, some being highly insoluble. Third, when soluble phosphorus sources such as those in manures and fertilizers are added to soil, they are readily transformed into unavailable forms and with time react further to become highly insoluble forms. Levels of different pools of soil P have been affected not only by soil properties and climatic condition but also by rate and type of P applied (Myungsu Park *et al.*, 2006).

The total P content in agricultural crops generally ranges from 0.2-0.5 per cent. Analysis of 3.65 million soil samples (1997 -

1999) indicates that 42 per cent samples are low, 38 per cent medium and 20 per cent high in phosphorus (Motsara, 2002). There is an increasing pressure to reduce the application of fertilizers in commercial agriculture and minimize non-point sources of pollution of both surface and ground waters. There was a selective crop response to nutrients in different soils and the responsiveness varied with soil nutrient status (Mulla *et al.,* 1992).

Continuous application of phosphorus results in buildup of this nutrient in the soil. The buildup of phosphorus depresses the availability of Zn and S. However, when nutrient additions are less than the requirement, the crop draws the soil nutrients. With such continuous withdrawals, the native resources diminish with time. Therefore, application of soil based rather than uniform rates of fertilizers is must. Further, Import of DAP increased from 0.6 million tonnes to 2.7 million tonnes during 2007-2008. Thus, to realize maximum benefits and reduce nutrient losses from fertilizers, they must be applied in the right quantity and source based on initial soil nutrient status.

In the light of the above facts, soils of Easter Dry Zone of Karnataka were analysed for available phosphorus and P fractions with an objective is to assess the status of available phosphorus and different phosphorus fractions in soils with different fertility levels.

Materials and Methods

To know the available phosphorus status, 250 soil samples were collected from 4 Agro-Ecological Systems (AES) of Eastern Dry Zone of Karnataka (Fig. 1) covering parts of Tumkur, Bangalore (Urban and Rural areas), Chikkaballapura and Kolar districts.

The details of the sampling areas are presented in Table 1 along with P status. Collected soil samples were air dried, powdered, passed through 2 mm sieve, stored in polythene bags and were analyzed for available phosphorus by adopting Jackson, 1973 procedure of Olsen's extraction method and Colorimetry for soils pH more than 6.5 and Brays extraction method for soils pH less than 6.5.

Based on the available phosphorus content, soils from EDZ of Karnataka were categorized as Very Low (VL: < 15 kg ha^{-1}), Low (L: 16-30 kg ha^{-1}), Medium (M: 31-45 kg ha^{-1}), High (H: 46-60 kg ha^{-1}) and Very high (VH: > 60 kg ha^{-1}) categories. Three soils from each of these categories were selected randomly and analyzed for different P fractions using standard procedure as given in 2.1.

Forms of phosphorus

Total phosphorus

The total phosphorus was extracted by digesting the soil with nitric acid and perchloric acid until a white residue was left. The residue was filtered and made to a known volume. Total phosphorus was then estimated by vanado-molybdo phosphoric yellow colour method (Hesse, 1971)

Organic phosphorus

Organic phosphorus was determined by deducting the sum of total inorganic phosphorus from total phosphorus as suggested by Mehta *et al.,* (1954).

Available phosphorus

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).

Forms of inorganic phosphorus

The method outlined by Peterson and Corey (1966) was followed to fractionate soil inorganic phosphorus.

Saloid bound phosphorus (Saloid P)

Exactly 0.5 g of soil was taken in to a 50 ml polyethylene centrifuge tube, 25 ml of 1 M NH_4Cl solution was added and shaken for 30 minutes. Saloid-P was estimated by molybdo-sulphuric acid reagent, using stannous chloride as reductant after taking the extract from supernatant solution after centrifugation in to an aliquot of 10 ml isobutyl alcohol. Blue colour intensity was measured at 660 nm using spectrophotometer.

Aluminium phosphorus (Al-P)

The soil residue left after saloid-P estimation was shaken for one hour with 25 ml of 0.5 M NH_4F (pH 8.2). The Al-P in the supernatant centrifuged suspension was determined by chloro-molybdic-boric acid reagent and chloro-stannous reductant. The intensity of blue colour developed was read in spectrophotometer at 660 nm.

Iron phosphorus (Fe-P)

The soil sediment from Al-P estimation was washed twice with 25 ml portion of saturated NaCl solution by shaking and centrifuging. The soil was then treated with 0.1 M NaOH and shaken for 17 hours and centrifuged. The supernatant solution was then treated with five drops of concentrated sulphuric acid. Phosphorus free activated carbon was used to remove suspended organic matter. The Fe-P content in the filtrate was determined by chloro-molybdic-boric acid reagent and chloro-stannous reductant. The intensity of blue colour developed was measured using spectrophotometer at 660 nm.

Reductant soluble phosphorus (R-P)

The soil residue from Fe-P estimation was washed twice with 25 ml of saturated NaCl solution by shaking and centrifuging. Soil was then suspended in 15 ml of 0.3 M sodium citrate solution and shaken for 15 minutes with 0.5 g sodium dithionate. The suspension was heated on a water bath at 80 ºC for a few minutes. Clear supernatant solution was decanted into a 50 ml volumetric flask after centrifugation. Soil was then washed twice with saturated NaCl and the washings returned to sodium citrate-dithionate extract which was taken for R-P estimation. Excess of citrate and dithionate were oxidised by 1.5 ml of 0.25 M $KMnO_4$ solution. The R-P was estimated by molybdate-sulphuric acid reagent with stannous chloride as reductant after taking the extract into an aliquot of 10 ml isobutyl alcohol. The blue colour intensity developed was diluted with equal quantity of absolute ethyl alcohol and read at 660 nm in spectrophotometer.

Occluded phosphorus (Occl-P)

The soil residue left out in the estimation of R-P was added with 25 ml of 0.1 M NaOH and shaken for one hour. Supernatant solution after centrifugation was taken for estimation of Occl-P by chloro-molybdic-boric acid reagent with chloro-stannous reductant.

Calcium phosphorus (Ca-P)

The soil residue after extraction of occluded phosphorus was washed twice with 25 ml of saturated NaCl solution and washings were discarded. Ca-P was extracted by using 0.25 M H_2SO_4 and shaking for one hour and centrifuging for five minutes. The phosphorus in supernatant solution was estimated by chloro-molybdic-boric acid reagent with chloro-stannous reductant.

Results and Discussion

P status

The nature and distribution of different forms of P provides useful information for assessing the available P status of soil. Estimation of available P indicates only the amount of P present in soil solution and soil surface which is available to plants but it does not indicate about the relative contribution of different fractions of P towards available P (Lungmuana *et al.,* 2012).

In Bangalore rural district, available phosphorus content ranged from 12.74 to 94.70 kg ha^{-1} whereas in Tumkur district, it ranged from 11.21 to 49.55 kg ha^{-1}. Similarly in Kolar distict, the available phosphorus content of soil ranged from 10.70 to 98.32 kg ha^{-1} and it ranged from 10.22 to 64.05 kg ha^{-1} in Chikkaballapura district (Table 1). The higher available P in soil may be due to buildup of P due to continuous addition of P fertilizer for the crops. Low in available P content of soil recorded may be due to regular cultivation with inadequate supply of phosphorus to crops. Higher levels of fertilizer P are needed in soils testing very low and low. Fertilizer P to be applied can be reduced when soils test very high in available P. Sharma *et al.,* (2012) reported the available P in Trans-Gangetic Plains, Upper Gangetic Plains, Middle Gangetic Plains and Lower Gangetic Plains was in the range of 6.7–85.1, 4.5–155.0 and 4.7–183.7, 2.2–112.0 kg ha^{-1}, respectively. Gurinderbir Singh and Sharma (2007) reported that the soils of Punjab showed low to high in available P.

Laxminarayana (2007) noticed Brays'1 available P status ranged from 6.56 to 10.93 kg P ha^{-1} in rice growing soils of Mizoram. Hasan (1996) reported that the available phosphorus status in Karnataka was ranged from low (16 %) to medium (3 %). Myungsu Park *et al.,* (2006) reported that the higher level of P remaining in the soil is accumulated by long-term annual application of compost and chemical fertilizers than by that of chemical fertilizer, and P accumulation might be a gradual saturation of the P-sorption capacity.

Categorization of soil available phosphorus (P_2O_5)

Categorization of soil available phosphorus (Table 2) found that 43.20 per cent of soil samples comes under low (<22.90 kg ha^{-1}) and 43.20 per cent of soil samples comes under medium (22.9-56.33 kg ha^{-1}) category, which represents 108 samples each, in the total 250 samples. High (> 56.33 kg ha^{-1}) category showed 13.60 per cent (34 soil samples). Percentage of soil samples under different category are arranged in the ascending order as follows:

Low = Medium > High

Phosphorus fractions

P fractions in soils of different phosphorus status were determined by selecting three soil samples from each tentatively classified categories *viz*., 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}) categories (Table 2).

The T-P, Org-P, RS-P, Occl-P and Ca-P content of soil increased as the phosphorus fertility status of soil increased from very low to very high (Fig. 2). Mean values of total-P ranged from 1218.90 to 3383.08 mg kg^{-1}. However, it ranged from 1082.09 to 1380.60, 1641.79 – 2089.55, 2164.18 – 2201.49, and 2761.19 – 4067.16 mg kg^{-1} in very low, low, medium, high and very high P fertility soils, respectively.

The mean organic-P values was lower (709.33 mg kg^{-1}) in very low P fertility soil and was higher (2819.10 mg kg^{-1}) in very high fertility soil. The values ranged 624.95 – 833.75, 1204.06 – 1500.75, 1664.60 – 1679.93, 1970.06 – 2210.73 and 2231.52 – 3461.85 mg kg^{-1} in very low, low, medium, high and very high P fertility soils, respectively.

Table.1 Soil available phosphorus status in EDZ of Karnataka

Sl. No.	Agro-Ecological Situations (Name of the taluk and village)	Available P_2O_5 (kg ha^{-1})	Previous crop grown
Bengaluru Rural District: Doddaballapurataluk			
1	Saslu	65.59	Maize
2	Saslu	24.50	Ragi
3	Thadalabandde	70.97	Ragi
4	Kankenahalli	61.63	Maize
5	Adakavala	26.37	Maize
6	Kadathippuru	84.81	Maize
7	Akkatammanahalli	16.37	Ragi
8	kattivasanahalli	32.74	Ragi
9	Doddabelavangala	31.20	Ragi
10	Sonnenahalli	69.10	Ragi
11	Turuvanahally,Tubgere	36.58	Ragi
12	Lakkasandra, Tubgere(H)	29.88	Maize
13	Tubgere(H)	67.45	Maize
14	Tubgere(H)	79.98	Maize
15	Hadonahally	58.12	Maize
16	Kansavadi	30.32	Ragi
17	Honnavara	18.90	Ragi
18	Purushanahally	13.73	Ragi
19	Hambalgere	18.13	Ragi
Bengaluru Rural District: Nelamangala taluk			
20	Hegunda	72.51	Ragi
21	Narasipura	39.66	Ragi
22	Bugudihally	29.77	Ragi
23	Makenahally	51.19	Ragi
24	Enchenahally	27.47	Ragi
25	Kundanahally	39.88	Ragi
26	Adivasahalli, Thyamagondadlu	16.15	Ragi
27	Thyamagondadlu	29.55	Ragi
28	Thyamagondadlu	13.29	Ragi
29	Thyamagondadlu	23.29	Ragi
30	Kalghatta	19.34	Red gram
31	Mallumghatteri	49.99	Ragi
32	Thippaganahalli	19.01	Ragi
33	Mallarabanavadi	26.59	Ragi
34	Basavanahalli	28.12	Ragi
35	Mylayahalli	27.90	Ragi
36	Rampura	69.32	Potato
Bengaluru Rural District: Devanahallytaluk			

37	Tindlu,	51.85	Red gram
38	Neraganahally	83.38	Ragi
39	Open filed Jail, Koramanagla	35.70	Ragi
40	Open filed Jail, Koramanagla	41.97	Vegetables
41	Open filed Jail,Koramanagla	54.05	Ragi
42	Open filed Jail,Koramanagla	17.91	Maize
43	Ahuti	35.92	Ragi
44	Vijayapura	48.56	Ragi
45	Vijayapura	12.74	Ragi
46	Patna	15.93	Ragi
47	Patna	26.92	Ragi
48	Patna (H)	29.77	Ragi
49	Sulibele	23.62	Ragi
50	Sulibele	34.83	Ragi
51	Teneuoor, Sulibele	30.87	Ragi
Bengaluru Rural District: Hoskotetaluk			
52	Chikkaallalagere	38.34	Ragi
53	Tharibehalli	16.48	Ragi
54	Kariberanahosahalli	94.70	Ragi
55	Kariberanahosahalli	31.75	Ragi
56	Kariberanahosahalli	13.62	Ragi
57	Hraluru, Haralemakanahalli	31.31	Ragi
58	Chimundanahalli	62.73	Ragi
59	Chimundanahalli	87.78	Ragi
60	Kannuralli	38.89	Ragi
61	Halapanahalli	62.95	Ragi
62	Lakondahalli	49.44	Ragi
63	Nandugudi	40.87	Ragi
64	Banahalli	25.71	Ragi
65	Indiganala	20.65	Ragi
66	VaddarahalliTq	22.85	Ragi
67	Araluru Tq	49.11	Ragi
Tumkur district : Gubbitaluk			
68	M.H. Patna,	51.85	Paddy
69	Ammanaghatta	32.30	Ragi
70	Channashettyhalli	13.95	Paddy
71	Gubbi	12.53	Paddy
72	Mattighata	13.51	Ragi
73	Nittur	11.21	Ragi
74	Kundernally	19.45	Ragi
75	Kundernally	14.39	Ragi
76	Doddaguni	17.58	Red gram
77	Doddaguni	15.60	Red gram
78	Godekeregate	14.39	Red gram
Tumkur district : Chikkanayakanahallitaluk			
79	Godekere Gate	11.54	Ragi
80	Chikkanayakanahalli	19.56	Ragi
81	Chikkanayakanahalli	19.34	Ragi
82	Maligehalli	17.36	Ragi
83	Balkere	23.73	Red gram

84	Sulakatte	17.69	Ragi
85	Sulakatte	21.09	Red gram
Tumkur district : Tiptur			
86	Mallenahally	18.68	Ragi
87	Tiptur	17.91	Ragi
88	Mattihally	18.68	Ragi
89	Shankrikoppalu	13.40	Red gram
90	Linganahally	15.38	Ragi
91	B.G Palya	18.79	Ragi
92	Sorekunte	13.73	Red gram
93	Sorekunte	49.55	Ragi
94	Dodderi	16.04	Ragi
95	Ballapura	20.43	Ragi
Kolar district			
96	Jodikrishnapura	28.89	Ragi
97	Achatnalli	65.48	Ragi
98	Kurkinarasapura	29.55	Ragi
99	Chowdenahalli	30.21	Ragi
100	Karinakanahalli, Malur	20.98	Ragi
101	Malur	98.32	Ragi
102	Malur	59.76	Ragi
103	Malur	82.72	Ragi
104	Malleshwarnagar	33.40	Ragi
105	Vakkaleri	89.54	Cauliflower
106	Chinnapura	57.57	Ragi
107	Dandiganahalli	101.40	Ragi
108	Beglihosahalli	24.72	Ragi
109	Ammerehally	30.76	Ragi
110	Beglibenjanahalli	33.40	Ragi
111	Chatrakodihally	61.52	Ragi
112	Mudiyalla	38.78	Ragi
113	Chatrakodihally	61.52	Ragi
114	Mudiyalla	38.78	Ragi
115	Vemgal	28.45	Ragi
116	Kurngal	68.33	Ragi
117	Harjenahally	64.82	Ragi
118	Nagunalu	57.13	Ragi
119	Nagunalu	44.16	Ragi
120	Busunahalli	53.39	Ragi
121	Busunahalli	97.01	Maize
122	Hurugali	58.99	Ragi
123	Oluru	6.59	Ragi
124	Marenahalli	35.92	Ragi
Kolardistrict:Mulabaglu			
125	Mudiyannur	48.01	Ragi
126	Kurudumalai	48.67	Ragi
127	Kadaripura	49.33	Ragi
128	Mulabaglu	69.76	Ragi
129	Kuruibarahally	60.20	Ragi
130	Nanagali	33.62	Ragi

131	Patrahalli	31.86	Groundnut
132	Pattarahally	19.12	Groundnut
133	Gummakal	36.25	-
134	Varadaganahalli	48.69	-
135	Varadaganahalli	32.96	-
136	Avani	32.63	-
Kolardistrict:Bangarpet			
137	Chikkankandahalli	45.13	Ragi
138	Kannimbelle	40.21	Ragi
139	Kannimbelle	70.75	Ragi
140	Baydbelle	22.85	Ragi
141	Nagashettahalli	30.32	Ragi
142	Nagulahally	46.91	Ragi
143	Kaysamballi	27.03	Ragi
144	Kaysamballi	21.97	Ragi
145	Lakshmisagar	33.51	Ragi
146	Badgurki	37.46	Ragi
147	Lekanahally	24.39	Ragi
148	Chikkayelasandra	27.25	Ragi
149	Dinakottur	29.88	Ragi
Kolar district: Malur			
150	Jagadenahalli,	50.87	Ragi
151	Jagadenahalli	29.55	Ragi
152	Thalikunte	46.36	Ragi
153	Thirumalahatti	37.57	Ragi
154	Dinnerihorohaali	51.19	Ragi
155	Dinnerihorohaali	34.61	Ragi
156	Allahalli	51.63	Ragi
157	Banahalli	53.83	Ragi
158	Chikkanayakanahali	40.87	Ragi
159	Chikkanayakanahali	39.33	Ragi
160	Chikkanayakanahali	47.02	Groundnut
161	Chikkanayakanahali	33.62	Ragi
162	Malur	73.74	Ragi
Kolardistrict:Srinivasapura			
163	Kappalli	43.50	Ragi
164	Kondamari	19.60	Ragi
165	Arganapalli	22.40	Ragi
166	Kurukongpalli	15.40	-
167	Bapapalli	13.20	Ragi
168	Bhimapguntapalli	15.00	Groundnut
169	Kempareddigarapalli	12.80	Ragi
170	Yerramarapalli	13.10	Ragi
171	Gollapalli	19.90	Tomato
172	Manchanaikakote	20.50	Ragi
173	Nalavanki	14.00	Ragi
174	Jodikottapalli	19.10	Ragi
175	Kasandra	26.70	Ragi
176	Kadirolaladdy	19.70	Ragi
177	Yelladdur	18.40	Ragi

178	Kuruppalli	13.70	Ragi
179	Kottapalli	14.30	Ragi
180	Muthagalli	43.90	Ragi
181	Neernalli	28.10	Ragi
182	Srinivasapura	22.80	Ragi
183	Champalli	10.70	Ragi
184	Champalli	19.10	Ragi
185	Doddapalli	23.80	Ragi
186	Nittur	11.70	Ragi
187	Kummagunta	17.60	Ragi
Chikkaballapura district:			
188	Muddenahally	11.32	Ragi
189	Arur	14.28	Ragi
190	Arur	19.12	Ragi
191	Hurinavarahalli	12.85	Ragi
192	Hurinavarahalli	23.95	Onion
193	Chikkanagarahalli	27.79	Potato
194	Mandikal	64.05	Beans
195	Gudimadlikallu	30.21	Popcorn
196	Mandikallu	10.88	Popcorn
197	Mandikallu	34.94	Popcorn
198	DesandraHosahally	19.34	Maize
199	Marsnalli	42.08	Ragi
200	Bungupe	10.22	Ragi
201	Kolaranahally	15.60	Ragi
Chikkaballapuradistrict:**Gauribidanur**			
202	Bandaralahalli	13.95	Maize
203	Basavapura	12.96	Maize
204	Bencchikkanahalli	34.61	Maize
205	Begalkapura	36.91	Maize
206	T.Bommasandra	55.04	Maize
207	Vodalveni	25.16	Maize
208	Demgattanahally	15.82	Maize
209	Gulur	31.37	Sunflower
Chikkaballapuradistrict:**Gudibande**			
210	Gudibande	11.80	Maize
211	Kondireddypalli	31.50	Ragi
212	Adinarayanahally,	11.60	Ragi
213	Chenduru	15.30	Ragi
214	Bichaganahally	43.90	-
215	Yarlekkanahally	14.10	Ragi
216	Chinnappanahally	15.10	Groundnut
217	Katenahally	16.80	Ragi
Chikkaballapuradistrict:Baagepalli			
218	Pottavarahally,	18.50	Ragi
219	Mittemari	14.70	Red gram
220	Burgamadgu	14.20	Red gram
221	Gollapalli	14.90	Bhendi
222	Achepalli	14.50	Red gram
223	Guttamindapalli	15.30	Groundnut

224	Sankatpalli	28.70	Maize
225	Sigalapalli	16.30	Groundnut
Chikkaballapuradistrict:Chintamani			
226	Hirepalya	43.50	Ragi
227	Gunnahalli	19.60	Ragi
228	Madabahalli	22.40	Ragi
229	Perumachanahalli	15.40	Ragi
230	Karatahalli	13.20	Ragi
231	Kachahalli	15.00	Ragi
232	Kuruburu	12.80	Ragi
233	Kuruburu	13.10	Potato
234	Kuruburu	19.90	Potato
235	Bachivaralahalli	20.50	Ragi
236	D.K.Halli	14.00	Ragi
237	Chikkakarakamakalahalli	19.10	Ragi
238	Karakamakanahalli	26.70	RAgi
239	Eraganapalli	19.70	Ragi
240	Erganapalli	18.40	Tomato
241	Raipalli	22.80	Ragi
242	Chintamani	10.70	Ragi
243	Mohammedpura	19.10	Ragi
244	Chikkatekahalli	11.70	Ragi
Chikkaballapuradistrict:Siddlaghatta			
245	Andignala,	13.70	Ragi
246	Bhudala	14.30	-
247	Bachahalli	43.90	Ragi
248	Kadranayakanahalli	28.10	Ragi
249	Doddatekahalli	23.80	Ragi
250	Kachanayakanahally	17.60	Ragi

Table.2 Categorization of available soil phosphorus (P_2O_5) in Eastern Dry Zone of Karnataka

AES/ Phosphorus fertility status	Category			Total number of samples
	Low (<22.9 kg ha^{-1})	Medium (22.9 – 56.33 kg ha^{-1})	High (> 56.33 kg ha^{-1})	
Bangalore rural	15	37	15	67
Tumkur	24	4	-	28
Kolar	25	49	18	92
Chikkaballapura	44	18	1	63
Total number of samples	108	108	34	**250**
Percentage of samples	**43.2**	**43.2**	**13.6**	

Table.3 Status of phosphorus fractions (mg kg^{-1}) in different phosphorus fertility soils of EDZ of Karnataka

P levels/ Soils	Total- P	Organic- P	S- P	Al-P	Fe-P	RS-P	Occluded- P	Ca-P
Very low (< 15 kg P_2O_5 ha^{-1})								
Soil 1	1380.60	833.75	63.23	164.31	109.87	188.49	12.30	8.65
Soil 2	1194.03	669.32	55.54	163.81	106.80	180.20	10.82	7.54
Soil 3	1082.09	624.95	54.99	150.04	105.96	132.56	7.38	6.21
Mean	**1218.90**	**709.33**	**57.92**	**159.39**	**107.54**	**167.08**	**10.17**	**7.47**
Range	**1082.09 -1380.60**	**624.95-833.75**	**54.99-63.23**	**150.04-164.31**	**105.96-109.87**	**132.56-188.49**	**7.38-12.30**	**6.21-8.65**
Low (15-30 kg P_2O_5 ha^{-1})								
Soil 1	2089.55	1500.75	51.69	148.56	102.89	250.63	17.71	17.32
Soil 2	1828.36	1339.04	46.19	92.98	84.43	234.05	16.23	15.44
Soil 3	1641.79	1204.06	46.00	84.12	75.49	205.06	13.28	13.78
Mean	**1853.23**	**1347.96**	**47.96**	**108.55**	**87.60**	**229.91**	**15.74**	**15.51**
Range	**1641.79-2089.55**	**1204.06-1500.75**	**46.00-51.69**	**84.12-148.56**	**75.49-102.89**	**205.06-250.63**	**13.28-17.71**	**13.78-17.32**
Medium (31-45 kg P_2O_5 ha^{-1})								
Soil 1	2201.49	1678.30	46.00	83.14	74.37	273.41	21.65	24.62
Soil 2	2164.18	1664.60	44.35	81.17	68.78	263.05	20.66	21.57
Soil 3	2164.18	1679.93	43.80	78.22	67.38	256.84	18.20	19.81
Mean	**2176.61**	**1674.28**	**44.72**	**80.84**	**70.17**	**264.43**	**20.17**	**22.00**
Range	**2164.18-2201.49**	**1664.60-1679.93**	**43.80-46.00**	**78.22-83.14**	**67.38-74.37**	**256.84-273.41**	**18.20-21.65**	**19.81-24.62**
High(46-60 kg P_2O_5 ha^{-1})								
Soil 1	2761.19	2207.38	43.80	77.73	63.74	298.26	39.85	30.43
Soil 2	2723.88	2210.73	42.52	76.25	47.81	287.91	30.01	28.65
Soil 3	2462.68	1970.06	41.61	72.31	42.78	285.84	23.61	26.47
Mean	**2649.25**	**2129.39**	**42.64**	**75.43**	**51.44**	**290.67**	**31.16**	**28.52**
Range	**2462.68-2761.19**	**1970.06-2210.73**	**41.61-43.80**	**72.31-77.73**	**42.78-63.74**	**285.84-298.26**	**23.61-39.85**	**26.47-30.43**
Very high (>60 kg P_2O_5 ha^{-1})								
Soil 1	4067.16	3461.85	41.42	72.31	38.58	364.55	49.69	38.76
Soil 2	3320.89	2763.95	40.87	71.82	36.62	325.19	48.70	33.74
Soil 3	2761.19	2231.52	38.31	61.49	35.23	316.91	45.75	31.98
Mean	**3383.08**	**2819.1**	**40.20**	**68.54**	**36.81**	**335.55**	**48.05**	**34.83**
Range	**2761.19-4067.16**	**2231.52-3461.85**	**38.31-41.42**	**61.49-72.31**	**35.23-38.58**	**316.91-364.55**	**45.75-49.69**	**31.98-38.76**

Table.4 Per cent contribution of different forms of phosphorus to total phosphorus

P levels	Org-P	S-P	Al-P	Fe-P	RS-P	Occl- P	Ca-P
Very low	58.19	4.75	13.07	8.82	13.70	0.84	0.61
Low	72.74	2.58	5.86	4.73	12.41	0.85	0.84
Medium	76.92	2.05	3.72	3.23	12.15	0.93	1.01
High	80.37	1.61	2.85	1.94	10.97	1.17	1.07
Very high	83.33	1.19	2.03	1.08	9.92	1.42	1.03

Fig.1 Agro-climatic Zones of Karnataka indicating soil sampled area of Eastern Dry Zone

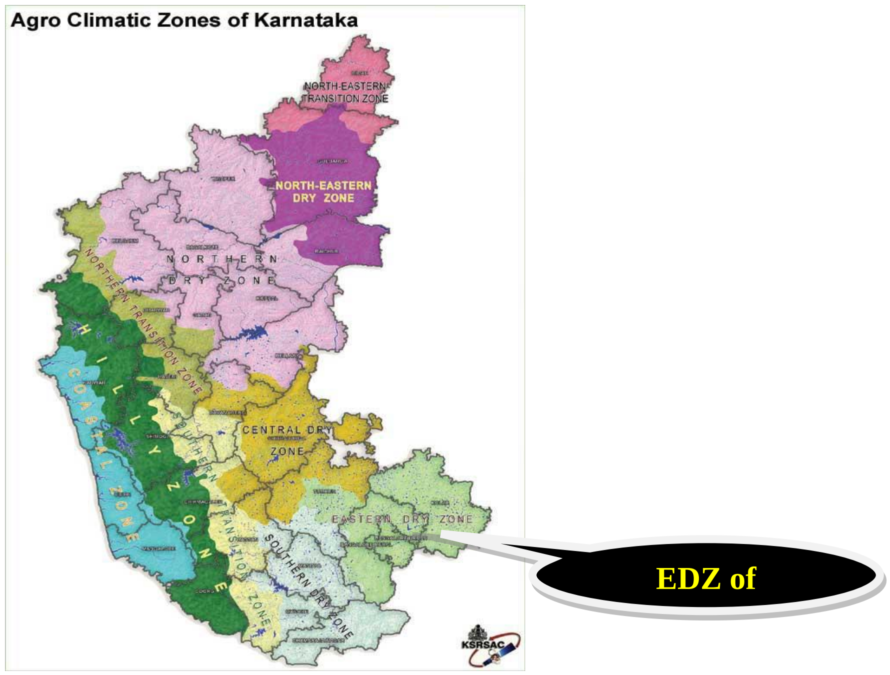
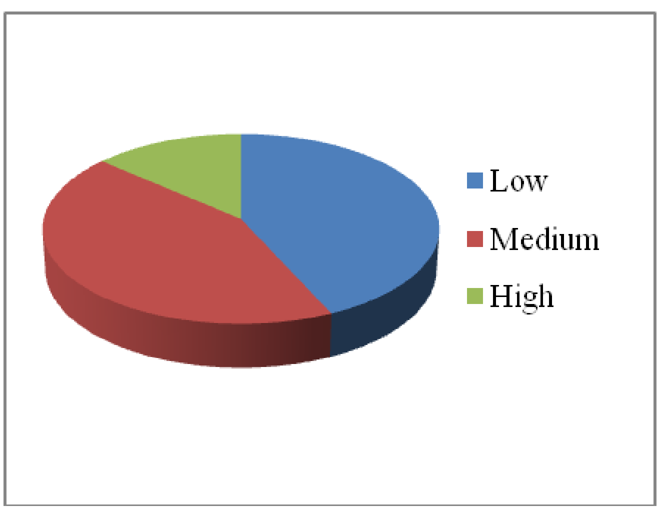


Fig.2 Categorization of soil available phosphorus content



Similarly, RS-P ranged from 132.56 – 188.49 (mean of 167.08), 205.06 – 250.63 (mean of 229.91), 256.84 – 273.41 (mean of 264.43), 285.84 – 298.26 (mean of 290.67) and 316.91 – 364.55 (mean of 335.55) mg kg^{-1}, in very low, low, medium, high and very high P fertility soils, respectively.

Further, Occl-P in very low, low, medium, high and very high P fertility soils showed mean value of 10.17 (range 7.38 – 12.30), 15.74 (range 13.28 – 17.71), 20.17 (range 18.20 – 21.65), 31.16 (range 23.61 – 39.85) and 48.05 (range 45.75 – 49.69) mg kg^{-1}, respectively. Ca-P in very low, low, medium, high and very high P fertility soils showed mean value of 7.47 (range 6.21 – 8.65), 15.51 (range 13.78 – 17.32), 22.0 (range 19.81 – 24.62), 28.52 (range 26.47 – 30.43) and 34.83 (range 31.98 – 38.76) mg kg^{-1}, respectively.

Unlike T-P, Org-P, RS-P, Occl-P and Ca-P, S-P, Al-P and Fe-P recorded decreasing trend as the phosphorus fertility status of soil increased from very low to very high. S-P content of soil ranged from 54.99 – 63.23 (mean of 57.92), 46.0 – 51.69 (mean of 47.96), 43.80 – 46.0 (mean of 44.72), 41.61 – 43.80 (mean of 42.64) and 38.31 – 41.42 (mean of 40.20) mg kg^{-1}, in very low, low, medium, high and very high P fertility soils, respectively.

Al-P in very low, low, medium, high and very high P fertility soils showed mean value of 159.39 (range 150.04 – 164.31), 108.55 (range 84.12 – 148.56), 80.84 (range 78.22 – 83.14), 75.43 (range 72.31 – 77.73) and 68.54 (range 61.49 – 72.31) mg kg^{-1}, respectively. Similarly, Fe-P content of soil ranged from 105.96 – 109.87 (mean of 107.54), 75.49 – 102.89 (mean of 87.60), 67.38 – 74.37 (mean of 70.17), 42.78 – 63.74 (mean of 51.44) and 35.23 – 38.58 (mean of 36.81) mg kg^{-1}, in very low, low, medium, high and very high P fertility soils, respectively.

Total- P, organic-P, reductant soluble-P, occluded-P and Ca-P content of soil increased as the phosphorus fertility of soil increased from very low to very high may be due to continuous addition of P sources to soil for the cultivation of crops which might have transformed the added P into these forms. The S-P, Al-P and Fe-P recorded decreasing trend as the phosphorus fertility status of soil increased from very low to very high which may be due to transformation of these S-P, Al-P and Fe-P forms in to non-labile forms resulting in their lower availability. The sequential distribution of P fractions in different gradient strips followed the order;

Very low P fertility soils: Total-P >Organic-P>RS-P>Al-P>Fe-P>S-P>Occluded-P>Ca-P

Low P fertility soils: Total-P>Organic-P>RS-P>Al-P>Fe-P>S-P>Occluded-P>Ca-P

Medium P fertility soils: Total-P>Organic-P>RS-P>Al-P>Fe-P>S-P>Ca-P>Occluded-P

High P fertility soils: Total-P>Organic-P>RS-P>Al-P>Fe-P>S-P>Occluded-P>Ca-P

Very high P fertility soils: Total-P>Organic-P>RS-P>Al-P>Occluded-P>S-P>Fe-P>Ca-P

Lungmuana *et al.,* (2012) reported that on an average the percentage contribution of different fraction to the total P was in the order of RS-P (28.2 %) > Fe-P (18.5 %) > Al-P (7.9 %) > Ca-P (5.8 %) > S-P (0.8 %) in surface acidic soils of rice growing areas of red and Laterite zone of West Bengal. Laxminarayana (2007) reported that the total P in various rice growing soils of Mizoram ranged from 132.30 to 365.80 mg kg^{-1} with a mean of 242.50 mg kg^{-1}. The sequential distribution of inorganic P fractions followed the order of RS-P (34.0 per cent) > Al-P (19.60 per cent) > Fe-P (15.80 per cent) > Ca-P (12.0 per cent) > S-P (2.46 per cent). The proportion of forms of phosphorus such as Ca-P, Al-P, Fe-P, reductant soluble-P, organic-P governs the response to applied P (Singh *et al.*, 2003).

Percent contribution of different forms of phosphorus to total phosphorus (Table 3) showed that organic-P, occluded-P and calcium-P fractions contribution to T-P, increased with increase in P fertility of soils, whereas S-P, Al-P, Fe-P and RS-P showed reverse trend. Organic-P fraction contributed highest per cent (58.19 to 83.33 per cent in very low to very high fertility soils, respectively) followed by RS-P (9.92 to 13.70 per cent in very high to very low fertility soils, respectively) and Ca-P contributed lower percent (0.61 to 1.03 percent in very low to very high fertility soils, respectively).

Available P_2O_5 in soils of EDZ of Karnataka ranged 10.22 to 98.32 kg ha^{-1}. Categorization of soil P recorded 43.20 per cent samples low and 43.20 per cent samples medium and 13.60 per cent samples belongs to high category. Total-P, organic-P, reductant soluble-P, occluded-P and Ca-P increased as the soil phosphorus fertility increased and reverse trend was noticed for saloid-P, Al-P and Fe-P fractions. Data on available P status and P fractions provide basis for soil specific P recommendation for sustainable P management both in irrigated and rainfed agriculture apart from reducing P losses and minimising pollution.

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, Sanjeev Kumar, S. Bhaskar, V.R.R. Parama and Naveen, D.V. 2017. Phosphorus Status in Soils of Eastern Dry Zone, Karnataka, India. *Int.J.Curr.Microbiol.App.Sci.* 6(11): 310-324. doi: https://doi.org/10.20546/ijcmas.2017.611.035