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Effect of 32 year long-term integrated nutrient management on soil p fractions and availability of phosphorus under sorghum-wheat cropping sequence in vertisol

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Abstract
Study on soil phosphorus (P) fraction is an important aspect in probing the mechanisms of soil P accumulation in farmland and mitigating its losing risk to the environment. We used a sequential extraction method to evaluate the impacts of long-term fertilization and organic manures incorporation on fractions of P of sorghum-wheat sequence in Vertisol. A permanent field experiment was conducted to investigate the effect of 32 year long-term integrated nutrient management treatments (control, Inorganics fertilizers only, Inorganics fertilizers + N substituted FYM, WCS, GM and Farmers practices). The P status of the different soil P-fractions (Saloid-P, Fe-P, Al-P, Red-P, Occl-P and Ca-P) were analyzed from 0-15 cm and 15-30 cm soil depths and their correlation with available-P was studied. It was found that a balanced application of 50% RDF + 50% N-FYM gave highest values of P-fractions followed by 50 % RDF + 50 % N- GM. However, Ca-P content found to be was decreased in treatments integrating organics and inorganics. The sequential order of dominance of different forms of P were Ca-P> Red-P>Al-P>Fe-P>Occl-P>Sal-P. The correlation study reveals that soil available-P is significantly influenced by saloid-P fraction under sorghum-wheat in Vertisol. The current investigation suggests the adoption of integrated nutrient management comprising 50 % RDF + 50 % N-FYM helps to circumvent P-deficiency under sorghum-wheat sequence in Vertisol.

Keywords: long-term, available-p, p-fractions, vertisol

Introduction

Phosphorus (P) is a major growth-limiting nutrient, and unlike the case for nitrogen, there is no large atmospheric source that can be made biologically available for root development, stalk and stem strength, flower and seed formation, crop maturity and production, N-fixation in legumes, crop quality, and resistance to plant diseases are the attributes associated with phosphorus nutrition (Khan *et al*., 2009) [1]. Phosphorus plays an indispensable biochemical role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement and several other processes in the living plant. It helps plants to survive winter rigors and also contributes to disease resistance in some plants (Sagervanshi *et al*., 2012) [15]. Crop yields are often limited by low P availability in soils, owing mainly to adsorption and precipitation reactions of both indigenous soil P and applied fertilizer P with iron (Fe), aluminium (Al) or Calcium (Ca) (Harris *et al.*,2006) [7]. Thus, soil scientist have more interest to study the phosphorus compound and their reactions in soil in content to the availability of phosphorus to crop plants. Phosphorus (P) availability and P fractions have long been of interest because of their importance in agricultural and aquatic environments. Many studies have revealed that long-term continuous application of fertilizers or manures increases soil P mobility. In soil, phosphorus occur in two forms *viz*., Active (Ca-P, Al-P, Fe-P) and Inactive (Reductant soluble-P, Occluded-P).These forms exist in all soils, but generally Al-P, Fe-P are more abundant in acids soils, and Ca-P dominance in neutral to alkaline soils. The Al-P and Fe-P can constitute 1-25% of total P in soils. Their proportion is higher in fertilized than unfertilized soils (Waldrip-Dail *et al*., 2009) [24]. The Ca-P can constitute 40-50% or even more of total P in many neutral to alkaline and calcareous soil. The reductant soluble P which is partially or completely dissolved at anaerobic conditions whereas occluded P consist of inner coat of material that prevent reaction of Fe-P, Al-P in solution. The beneficial effects of organic manures like FYM, WCS and green manures are universal; yet the effects on different crops grown during different seasons may be different, because the soil organic matter performs different functions at its different stages of decomposition. Build up in soil organic carbon *i.e.*

humus due to organic manuring improves the physical properties of the soil while at later stages it is mineralized and nutrients are released into the soil system. Therefore, it is imperative to study the direct and residual effect of organic manuring in a cropping system as a whole. Hence, understanding of nutrient transformation after organic material incorporation in combination with chemical fertilizers on long-term basis is essential in developing management practices that can lead to more efficient use of organic source of nutrients in a cropping sequence.

The long-term field experiments provides a means of better understanding of nutrient dynamics in soils. So the current investigation of inorganic P transformations was carried out in 32 year long-term permanent field experiment under sorghum-wheat cropping system in Vertisol. The objectives of the present study were-

1. To study the forms of phosphorus as influenced by long-term use of integrated nutrient management.
2. To study the correlation between forms of phosphorus and available phosphorus.

Material and Methods

The ICAR project on Integrated Farming Research at M.P.K.V., Rahuri, Maharashtra has initiated a permanent long-term field experiment during 1984-1985 in cereal-cereal (Sorghum-Wheat) cropping system with 12 treatments and four replications in a randomized block design. The experiential soil belongs to Vertisol order and otur series, which is a member of fine, montmorillonic, iso-hyperthermic family of *Typic Haplusterts*. The initial soil properties during 1984 were alkaline *p*H (8.2), EC (0.27), soil organic carbon (0.64%), available nitrogen (153 kg ha^{-1}), available phosphorus (14.20 kg ha^{-1}), available potassium (705 kg ha^{-1}) and available micro nutrients of Fe, Mn, Zn and Cu was 12.9, 22.1, 0.87 and 3.27 mg kg^{-1}. The treatments of organics *viz*., Farm yard manure (FYM), Wheat cut straw (WCS) and Green manure (GM-*Dhaincha* loopings) were used for the substitution of 50 and 25% Nitrogen levels. Nitrogen was applied in two splits to both the crops, half at time of sowing and remaining half at 30 and 21 days after sowing of sorghum and wheat respectively. The FYM, WCS and Dhaincha loopings were incorporated in soil before ploughing in summer. This ongoing long-term permanent field experiment was selected to study the levels of different fractions of phosphorus by molybdo-phosphate original methods given by Change and Jackson (1957) [4] were used with few modification that suggested by Peterson and Corey (1966) [12] and their correlation with soil available P.

Results and Discussion

The results obtained on P fractions, available-P and correlation study after 32 year long-term application of integrated nutrient management are presented in table 1 to 4 and fig 1 to 7.

Saloid phosphorus (Sal-P)

The treatment receiving (50% RDF + 50% N-FYM) recorded significantly the highest Sal-P (20.96 mg kg^{-1}) followed by treatment comprising 50% RDF + 50% N-GM (19.05 mg kg^{-1}).The treatments receiving chemical fertilizers alone T_2 to T_5 observed higher Sal-P 11.43 to 18.10 mg kg^1 respectively over control which resulted the lowest value of saloid-P (6.67 mg kg^{-1}). Its content in surface samples (0-15 cm) varied from 6.67 to 20.96 mg kg^{-1}) and sub-surface (15-30 cm) varied from 5.74 to 18.85 mg kg^{-1}. Similar findings were also reported by Rajeswar *et al*. (2009) [12] who found that available P decreased gradually from surface to subsurface layer and its content was higher at surface layer. The amount of P recovered in all P fractions was found to increase significantly with the application of inorganic fertilizers and their combined use with organics over control in soil.

Table 1: Saloid-P and Aluminium-P (mg kg^{-1}) as influenced by long-term integrated nutrient management

Tr No.	*Kharif* sorghum	*Rabi* wheat	Saloid-P		Al-P	
			0-15 cm	15-30 cm	0-15cm	15-30 cm
T_1	Control	Control	6.67	5.74	33.00	31.00
T_2	50 % RDF	50 % RDF	11.43	10.61	58.00	57.00
T_3	100 % RDF	100 %RDF	14.29	12.88	83.00	81.00
T_4	75% RDF	75% RDF	12.38	11.22	66.00	61.75
T_5	100% RDF	100% RDF	18.10	17.80	116.00	113.50
T_6	50%RDF+50% N-FYM	100% RDF	20.96	18.85	133.00	131.75
T_7	75%RDF+25% N-FYM	75% RDF	16.19	15.61	100.00	98.00
T_8	50%RDF+50% N-WCS	100% RDF	13.34	12.51	75.00	73.25
T_9	75%RDF+25% N-WCS	75% RDF	15.24	14.38	91.00	85.50
T_{10}	50%RDF+50% N-GM	100% RDF	19.05	18.63	125.00	120.00
T_{11}	75%RDF+25% N-GM	75% RDF	17.15	16.96	108.00	103.50
T_{12}	Farmers practice	Farmers practice	9.53	8.23	50.00	45.75
	S.E(m)±		0.012	0.072	1.160	0.836
	CD at 5%		0.036	0.212	3.404	2.452

Aluminium bound Phosphorus (Al-P)

The data presented in (Table. 1 and Fig. 2) showed that Al-P was significantly influenced by different INM practices. The lowest value (33 mg kg^{-1}) was recorded in control (T_1). The significantly superior value was recorded in treatment comprising of conjoint use of chemical fertilizers with FYM 133.0 mg kg^{-1} (T_6). It was also observed that treatments which comprising organics (T_{10}, T_{11}, T_7, T_9, T_8) shows higher values (125, 108, 100, 91, 75 mg kg^{-1} respectively) of Al-P content over rest of treatments which supplying inorganic fertilizers alone. The higher Al-P obtained in FYM treatment as compared to control may be due to the solubilization effect of certain organic acids which are released during the FYM decomposition as reported by Patel *et al*. (1993) [13].

The Al-P concentration was found to be drastically varied, ranged from 33 to 133 mg kg^{-1} in 0-15 cm and 31 to 131.75 mg kg^{-1} in 15-30 cm depths. These findings corroborate with those of Singh *et al*. (2010) [17]; Trivedi *et al*. (2010) [13] and Tiwari *et al*. (2012) [19].

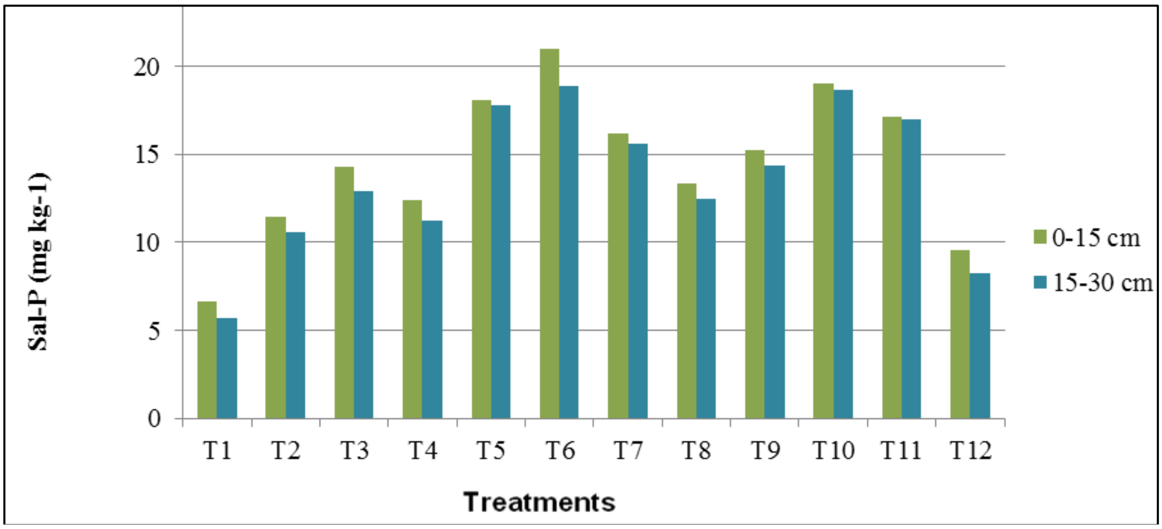

Fig 1: Saloid-P as influenced by long-term INM under sorghum –wheat cropping sequence

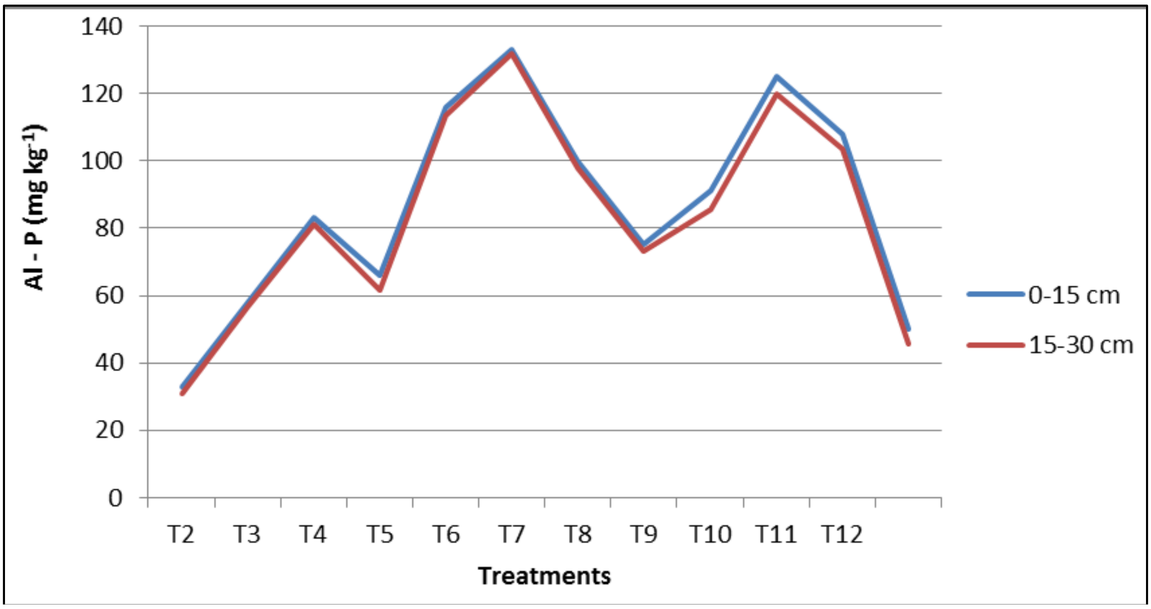

Fig 2: Al-P as influenced by long-term INM under sorghum–wheat cropping sequence

Iron bound phosphorus (Fe-P)

The data presented in (Table 2 and Fig. 3) showed that the Fe-P was found to be significantly highest in the treatment 50% RDF + 50% N-FYM (101.72 mg kg^{-1}) followed by 50% RDF + 50% N-GM (89 mg kg^{-1}) which were found to be significantly superior to all other treatments. Similar trends found in lower depth. The results further indicated that the significantly highest Fe-P values varied from 101.72 to 100.64 mg kg^{-1} in 0-15 cm and 15-30 cm soil depth, respectively. Similar results were reported by Bhakare and Tuwar (2006) [3].

Table 2: Fe-P and Red-P as influenced (mg kg^{-1}) as influenced by long-term integrated nutrient management

Tr. No.	*Kharif* sorghum	*Rabi* wheat	Fe-P		Red-P	
			0-15 cm	15-30cm	0-15 cm	15-30cm
T_1	Control	Control	25.43	24.37	39.00	29.00
T_2	50 % RDF	50 % RDF	38.15	37.05	91.00	56.00
T_3	100 % RDF	100 %RDF	50.86	49.74	130.00	80.00
T_4	75% RDF	75% RDF	38.15	37.05	104.00	60.75
T_5	100% RDF	100% RDF	76.29	75.14	182.00	112.50
T_6	50%RDF+50% N-FYM	100% RDF	101.72	100.64	208.00	130.75
T_7	75%RDF+25% N-FYM	75% RDF	63.33	62.24	156.00	97.00
T_8	50%RDF+50% N-WCS	100% RDF	38.15	37.11	117.00	72.25
T_9	75%RDF+25% N-WCS	75% RDF	50.86	49.37	143.00	84.50
T_{10}	50%RDF+50% N-GM	100% RDF	89.00	88.63	195.00	119.00
T_{11}	75%RDF+25% N-GM	75% RDF	76.29	74.04	169.00	102.50
T_{12}	Farmers practice	Farmers practice	38.15	37.18	78.00	44.75
	S.E(m)±		0.089	0.011	1.097	0.806
	CD at 5%		0.260	0.033	3.216	2.363

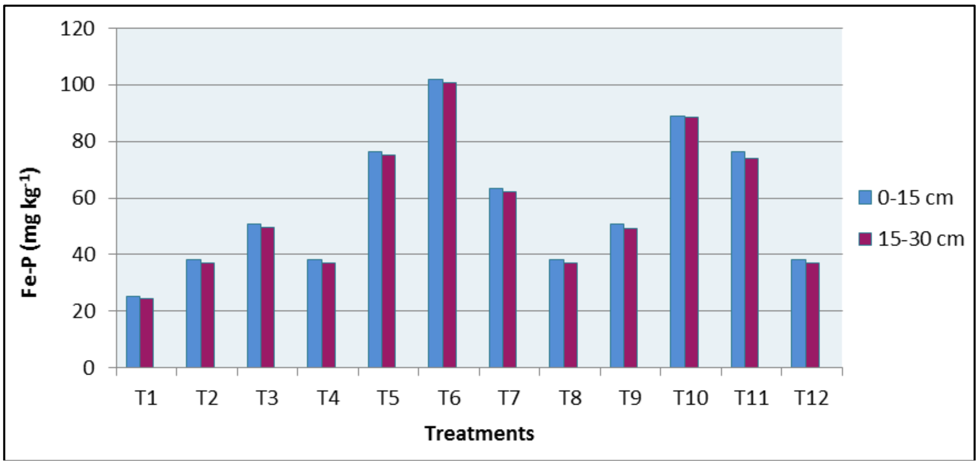

Fig 3: Fe-P as influenced by long-term INM under sorghum–wheat cropping sequence

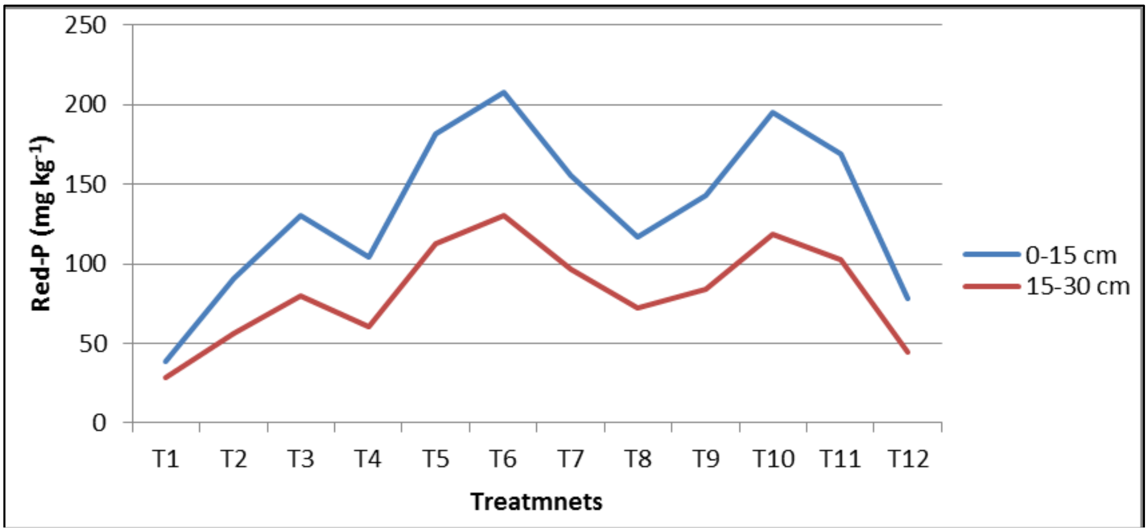

Fig 4: Red-P as influenced by long-term INM under sorghum–wheat cropping sequence

Reductant bound phosphorus (Red-P)

The significantly maximum (208 mg kg^{-1}) Red-P recorded after wheat harvest is under T_6 treatment (50% RDF + 50% N-FYM). The data presented in table 2 and fig. 4 shows that the Red-P of the treatments comprising organics shows higher values (195, 169, 156, 143, mg kg^{-1}) compared to treatments with only inorganics except T_5 (182 mg kg^{-1}) and T_3 (130 mg kg^{-1}) over lowest value in control (39 mg kg^{-1}). Similar trends were found in lower depth (15-30 cm).

Graded dose of NPK fertilizers caused an increase in Red-P as compared to control. The values of Red-P were lower than that of Ca-P but higher than the Al-P and Fe-P, which may be attributed to the low sesquioxides. These findings followed the results reported by Kolambe (1992) [9]; Nale (1996) [10]; Bhakare and Tuwar (2006) [3]. Reductant soluble P content in the experiential soil profile ranged from 39 to 208 mg kg^{-1} in surface soil (0-15 cm) and decreased in lower depth (15-30 cm) 29 to 130 mg kg^{-1}. Similar trend in profile was also reported by Singh and Omanwar (1987) [18]; Dongale (1993) [5] and Trivedi *et al*. (2010) [13].

Occluded phosphorus (Occl-P)

The significantly highest (32.81 mg kg^{-1}) Occl-P form after wheat harvest was obtained in the plot receiving the treatment 50% RDF + 50% N through FYM. The treatments comprising chemical fertilizers and organics showed higher values than treatments receiving chemical fertilizers alone compared to lowest value (11.40 mg kg^{-1}) in control. This may be due to the solubilizing effects of organic acid produced as a result of organic manures decomposition maintained throughout the 32 years in this treatment. Present findings were also in the line of earlier observations made by Rane and Patel (1989) [14]. The same trend was also followed in subsurface depth (15-30 cm).

Table 3: Occl-P and Ca-P as influenced (mg kg^{-1}) as influenced by long-term integrated nutrient management

Tr. No.	*Kharif* sorghum	*Rabi* wheat	Occl-P		Ca-P	
			0-15 cm	15-30cm	0-15 cm	15-30cm
T_1	Control	Control	11.40	10.38	363.38	360.71
T_2	50 % RDF	50 % RDF	17.06	16.16	337.68	336.29
T_3	100 % RDF	100 %RDF	22.75	21.05	239.90	238.32
T_4	75% RDF	75% RDF	18.37	17.28	283.20	280.26
T_5	100% RDF	100% RDF	29.76	28.64	312.48	311.42
T_6	50%RDF+50% N-FYM	100% RDF	32.81	31.23	195.73	194.31
T_7	75%RDF+25% N-FYM	75% RDF	23.62	22.56	202.10	201.08

T_8	50%RDF+50% N-WCS	100% RDF	19.24	18.15	228.28	225.60
T_9	75%RDF+25% N-WCS	75% RDF	23.18	22.37	217.69	212.23
T_{10}	50%RDF+50% N-GM	100% RDF	30.63	29.27	172.87	171.87
T_{11}	75%RDF+25% N-GM	75% RDF	27.12	26.27	198.07	197.06
T_{12}	Farmers practice	Farmers practice	13.13	11.56	352.29	351.67
	S.E(m)±		0.045	0.049	1.623	0.448
	CD at 5%		0.131	0.145	4.760	1.314

Calcium bound phosphorus (Ca-P)

The data on Ca-P fraction after the completion of 32 year long-term application of conjuctive use of fertilizers along with organic manures are furnished in (Table 3 and Fig.6) showed that maximum concentration (363.38 mg kg^{-1}) of Ca-P was recorded in control (T_1) and minimum concentration (195.73 mg kg^{-1}) is observed in T_6 (50% RDF + 50% N-FYM). On the other hand, plots receiving fertilizers along with organic manures (FYM, WCS and GM) recorded substantially lower Ca-P content over control. The results indicates clearly that as the rhizosphere pH decreases due to increase in plant biomass by various treatments and the loading of long-term organic manures causes decreasing trend of Calcium bound P status in the experiential plots due to solubilization effects. Similar trends were found in lower depth (15-30 cm).

It is observed that Ca-P concentration declined slightly with soil depth, it varies from to 363.38 to 194.31 mg kg^{-1} and 360.71 to 201.08 mg kg^{-1} in 0-15 cm and 15-30 cm soil depths respectively. The use of P fertilizer in combination with N and K raised the soil P content in all the fractions; the increase being more at higher rates of P addition. The continuous use of phosphatic fertilizers in cropping system resulted in build up of phosphate in soil and it got transformed into different inorganic P fractions. Similar results were also reported by Singh *et al.* (2010) [17]. The Ca-P was the major inorganic P fraction in all the treatment plots because Vertisols are reported to have large amounts of P as Ca-P, irrespective of nature and kind of added fertilizer due to the more stabilized nature of calcium system under high pH (Jaggi, 1991) [8]. The Ca-P and Red-P are found to be dominating P forms in Vertisol. Combined use of fertilizers with manures influences the form and availability of soil phosphorus in many ways. The proportion of forms of phosphorus such as Ca-P, Al-P, Fe-P, Red-P, organic-P governs the response to applied P (Singh *et al.*, 2003) [20].

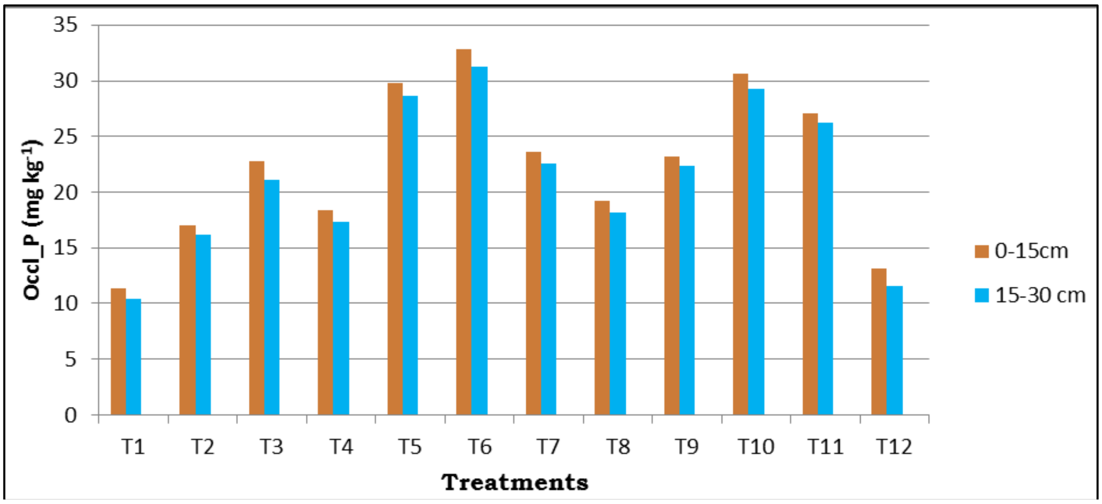

Fig 5: Occl-P as influenced by long-term INM under sorghum –wheat cropping sequence

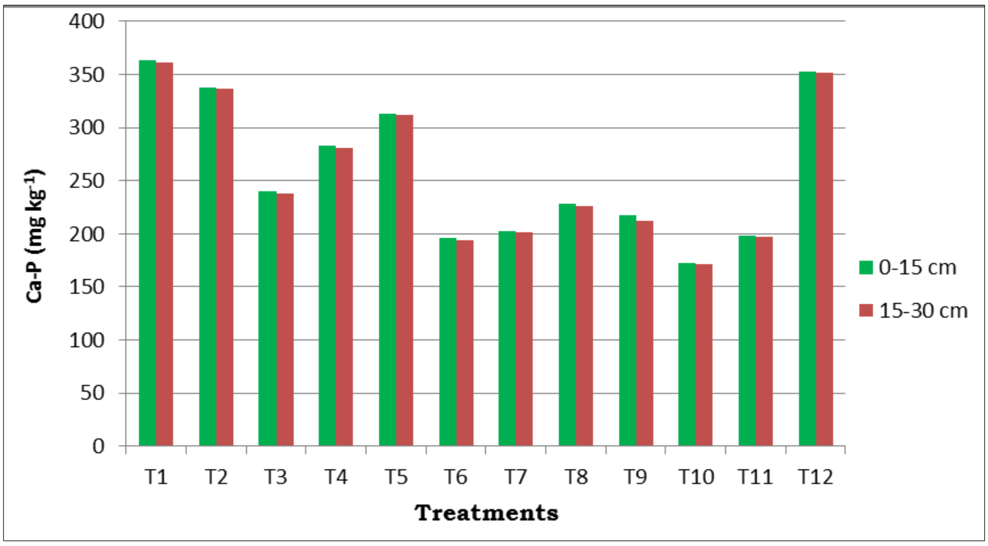

Fig 6: Ca-P as influenced by long-term INM under sorghum–wheat cropping sequence

Total phosphorus (Total-P)

The data presented in the (Table 4) showed higher concentration (1180.96 mg kg^{-1}) of total-P was recorded in T_6 (50% RDF + 50% N-FYM). Plots, which receiving inorganic fertilizers alone and control resulted in the lowest value of total-P as compared to other integrated treatments. On the other hand, plots receiving chemical fertilizers along, with organics (1180.69, 1049.86, 977.43, 1013.29, 1129.23 and 1082.71 in T_6, T_7, T_8, T_9, T_{10}, and T_{11}) recorded substantially higher total-P content.

It was also observed that a decrease trend in concentration of total-P in all treatments from surface to sub surface layer of experiential soil. The highest content of total-P in surface layer is due to higher organic matter exhibiting in the 0-15 cm layer of the soil. This observation is in conformity with the findings of Trivedi *et al*. (2010) [13].

Table 4: Total-P and Available-P as influenced (mg kg^{-1}) as influenced by long-term integrated nutrient management

Tr No.	*Kharif* sorghum	*Rabi* wheat	Total-P		Available-P	
			0-15 cm	15-30 cm	0-15 cm	15-30 cm
T1	Control	Control	729.57	728.06	6.51	5.43
T2	50 % RDF	50 % RDF	882.15	881.15	17.75	16.65
T3	100 % RDF	100 %RDF	1004.92	1003.10	19.97	18.86
T4	75% RDF	75% RDF	924.31	923.12	18.32	17.29
T5	100% RDF	100% RDF	1105.52	1104.50	23.00	22.26
T6	50%RDF+50% N-FYM	100% RDF	1180.69	1179.27	24.93	23.96
T7	75%RDF+25% N-FYM	75% RDF	1049.86	1048.68	21.36	20.24
T8	50%RDF+50% N-WCS	100% RDF	977.43	975.27	19.80	17.29
T9	75%RDF+25% N-WCS	75% RDF	1013.29	1012.06	21.08	19.96
T10	50%RDF+50% N-GM	100% RDF	1129.23	1127.75	23.55	22.81
T11	75%RDF+25% N-GM	75% RDF	1082.71	1081.19	22.17	20.88
T12	Farmers practice	Farmers practice	837.71	835.45	16.42	15.40
	S.E(m)±		0.012	0.206	0.209	0.226
	CD at 5%		0.034	0.604	0.614	0.664
	Initial (1984-85)				14.20	

Available-P

The available soil phosphorus was significantly increased upto 24.93 kg ha^{-1} in T_6 from 14.20 kg ha^{-1} as recorded at initial stage during 1984-85. It was observed to be significantly the highest over control (6.5 kg ha^{-1}). The average available phosphorus in soil where chemical fertilizers applied (T_2 to T_5) 19.46 kg ha^{-1} and further by integration with organics treatment (T_6 to T_{11}) average available phosphorus in soil is 22.14 kg ha^{-1} in (Table 4). The application of 50 per cent NPK through chemical fertilizer + 50 per cent N through FYM (T_6) recorded 8.3 percent more available P status than use of 100 percent chemical fertilizers (T_5).

It is observed that application of nutrients with integration of chemical fertilizer and FYM showed higher available phosphorus status. Similar results were observed by Santhy *et al.* (1998) [8]. The increase in available phosphorus status is due to FYM, being a direct source of phosphorus and it might have also solubilized the native phosphorus in the soil through release of various organic acids. Tolanur and Badanur (2003) [14] and Bajpai *et al.* (2006) [2] also supported that organic manure with inorganic fertilizers had the beneficial effect on increasing the phosphate availability.

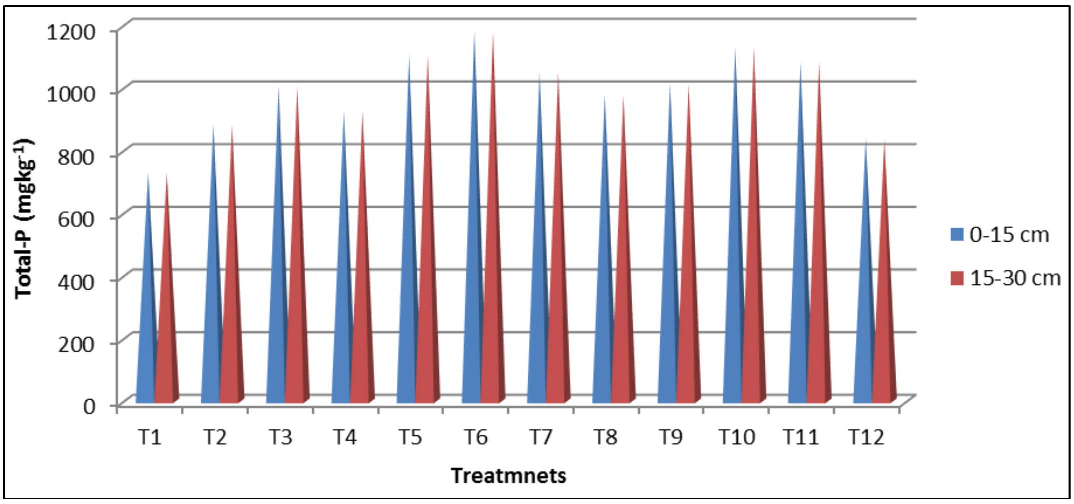

Fig 7: Total-P as influenced by long-term INM under sorghum–wheat cropping sequence

Correlation between P-fractions and available-P

Amongst the inorganic forms of P, Saloid-P showed highly significant positive correlation with available P (r=0.924**) and (r=0.923**) in 0-15 cm and 15-30 cm respectively followed by Red-P (r=0.918**), Al-P (r=0.891**), occl-P (r=0.878**), Fe-P (r=0.795**) at surface layer of soil (0-15 cm). Similar trend in correlations was observed in sub surface layer (15-30 cm). The correlation study between inorganic phosphorus fractions confirms that all phosphorus fractions *viz.*, Sal-P, Fe-P, Al-P, Red-P and Occl-P showed significant positive correlation except Ca-P. Similar results were reported by Gajbhiye (2001) [6].

Table 5

P fractions	Sal-P		Fe-P		Al-P		Red-P		Occl-P		Ca-P		Total-P	
Soil depth	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Av. P	0.924**	0.923**	0.795**	0.819**	0.891**	0.897**	0.918**	0.901**	0.872**	0.884**	0.742**	-0.715**	0.939**	0.941

Conclusion
The long term application of inorganic fertilizers with farm yard manure helped to enhance and improved the phosphorus fractions. Correlation study confirms that saloid-P contributes significantly highest correlation with available-P in Vertisol. Due to long-term phosphorus fertilizer application through the best INM practice of 50 percent NPK through chemical fertilizers with 50 percent N through FYM in Vertisol resulted in built up of available-P status from very low to high. This indicates that, based on the soil testing and status of available-P, there is a scope to save the phosphatic fertilizers in near future for field crops in Vertisol.

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