__Original Research Article__

Impact of long-term use of fertilizers and manure on distribution of soil-inorganic phosphorus fractions in a Vertisol

ABSTRACT

The field experiment was conducted during the kharif season under the AICRP on Long-Term Fertilizer Experiment at the Research Farm, Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur (M.P.), India. The investigation was carried out to assess the distribution of P fractions in Vertisol after the harvesting of the soybean crop. Eight treatments were imposed with four replications in a simple randomized block design. The treatments were applied in combination with different doses of fertilizer viz., T1 (50% NPK), T2 (100% NPK), T3 (150% NPK), T4 (100% N), T5 (100% NP), T6 (100% NPK+FYM), T7 (100% NPK-S), and T8 (control). Through the findings, the soil pH and electrical conductivity (dS m-1) did not show significant changes even after the long-term application of various fertilizer levels compared to their initial values. The treatment with 100% NPK + FYM exhibited the highest organic carbon (g kg-1) content and available N, P, and K (kg ha-1) content over the control. The various forms of phosphorus in the soil were observed in the following order: Ca-P > Fe-P > Al-P > Occluded-P > Saloid-P . The Ca-P content was highest when 100% NPK fertilizer and farmyard manure (FYM) were used together. The analysis showed that the presence of saloid-P significantly influences the availability of phosphorus in Vertisol soil. Based on the current investigation, it is recommended to use integrated nutrient management, which includes both 100% NPK fertilizer and FYM, to prevent phosphorus deficiency in soybean cultivation in Vertisol.

Keywords: *FYM, LTFE, Inorganic Fertilizer, Phosphorus fraction, Vertisol.*

INTRODUCTION

Fertilisers are key inputs for enhancing agricultural output; however, their continuous and improper application negatively impacts the health of the soil. Dwivedi et al. (2007) state that long-term fertiliser experiments enable precise monitoring of changes in soil fertility and crop yield.This facilitates the solution of highly complex issues related to soil fertility management. There arises a concern that the prolonged application of chemical fertilisers could significantly reduce the fertility of the soil. The integration of organic manures with inorganic fertilizers has the potential to not only maintain crop productivity but also enhance soil health and nutrient utilisation efficiency (Thakur et al., 2011).

Phosphorus is an important nutrient for maintaining the security of the global food supply, and efficient utilization of phosphorus is very important because of its limited availability (Roberts and Johnston., 2015). In black soils, a significant portion of the P fertilizer applied (around 80-85%)

becomes fixed in the soil, while only a small fraction (15-20%) becomes accessible to plants, as reported by Dubey *et al*., (2016). To ensure the prudent use of P fertilizer, understanding how applied P transforms into different forms such as saloid-P, aluminum P (Al-P), iron P (Fe-P), occluded P, and calcium P (Ca-P) is crucial. The availability of P is determined by the distribution of these inorganic P compounds, as highlighted by Bairwa *et al*., (2021).

Phosphorus in soils is present both in organic as well as in inorganic compounds with aluminium (Al), iron (Fe), and calcium (Ca). The phosphorus supply to plants is influenced by these substances (Tan, 1998). The phosphorus sorption isotherm facilitates the prediction of the efficiency with which crops will utilise the labile inorganic P (fertiliser P) supply. It is generally known that phosphate adsorption is influenced by a variety of soil characteristics, including clay concentration, $CaCO_3$, organic matter, Al and Fe content, CEC, and the sources of P that are added to the soil. The long-term fertilizer experiment was conducted with major attention to the yield performance of crops that are under balanced and imbalanced manure and fertilizer applications in the soil fertility management of a cropping sequence (Katyal 2015). In a permanent manorial experiment with the long-term fertilizer experiment provides a very good opportunity to address the issue.

MATERIALS AND METHOD

Experimental site, Climate and Soil characteristics

The All India Coordinated Research Project on Long Term Fertilizer Experiment, funded by ICAR, commenced in 1972 at the Department of Soil Science, Jawaharlal Nehru Krishi Vishwa Vidyalaya in Jabalpur, Madhya Pradesh, India. The Jabalpur region has a distinct semi-arid and subtropical climate with dry summers and cold winters. The experimental site is approximately 393 meters above mean sea level at 23° 10' N latitude and 79° 57' E longitude. The average temperature throughout the winter season, which runs from November to February, is 4°C to 33°C, with a relative humidity range of 70% to 90%. Generally speaking, the months of March to June are dry and warm. The temperature can rise as high as 45°C in the summer and fall to below 5°C or 10°C in the winter. Mid-June through mid-September is the monsoon season. The area receives 1350 mm of rain on average each year. The experimental field featured medium black soil from the Kheri series, classified as fine montmorillonitic hyperthermic Typic Hapluster, with a soil pH of 7.6, electrical conductivity of 0.18 dS m^{-1} (measured at a 1:2.5 soil-to-water ratio), soil organic carbon content of 5.7 g kg^{-1}, available nitrogen at 193 kg ha^{-1}, available phosphorus at 7.6 kg ha^{-1}, and available potassium at 370 kg ha^{-1}. This soil had a clay texture.

Table 1. Initial soil properties of the experimental site

Soil properties	Value	Reference
pH1:2.5	7.60	Jackson (1973)
Electrical conductivity (EC1:2.5)	0.18 dS m^{-1}	Jackson (1973)
Organic carbon	5.7 g kg^{-1}	Walkley and Black (1934)
Available N	193 kg ha^{-1}	Subbiah and Asija (1956)
Available P	7.60 kg ha^{-1}	Olsen *et al*. (1954)
Available K	370 kg ha^{-1}	Muhr *et al*. (1965)
Various phosphorus fractions		Peterson and Corey (1966)
Saloid-P	2.6 mg kg^{-1}	
Al-P	26.2 mg kg^{-1}	
Fe-P	41.5 mg kg^{-1}	
Occluded-P	36.5 mg kg^{-1}	
Ca-P	87.5 mg kg^{-1}	

Treatments details

Table 2. The experiment comprised eight different treatments:

	Treatments

T_1	50% NPK
T_2	100% NPK
T_3	150% NPK
T_4	100% NP
T_5	100% N
T_6	100% NPK + 5 t FYM ha^{-1}
T_7	100% NPK – S (Sulphur-free)
T_8	Control

Table 3.Technical programme

Location	:	Research Farm, Department of Soil Science and Agricultural Chemistry, JNKVV, Jabalpur (M.P.)
Crop	:	Soybean
Treatments	:	8
Replications	:	4
Experimental design	:	Randomized Block Design (RBD)
Experimental Area	:	146m x 58 m
Plot size	:	17 m X 10.8 m
Space between replication	:	2 meters
Space between plots	:	1 meter
Fertilizer doses (kg ha^{-1}) NPK	:	20:80:20 through Urea, SSP/DAP and MOP.

Each treatment was replicated four times in a randomized block design. For soybean cultivation, the recommended fertilizer doses based on the initial soil test values were 20 kg N, 80 kg P_2O_5, and 20 kg K_2O per hectare. Urea, single superphosphate, and muriate of potash were used as the sources of nitrogen, phosphorus, and potassium, respectively. In the sulphur-free treatment (T_7), diammonium phosphate (DAP) was used instead of single superphosphate as the source of phosphorus. Farmyard manure was applied at a rate of 5 tons per hectare per year, exclusively during the kharif season for soybean crop. All recommended agricultural practices were followed to cultivate soybeans as per standard recommendations.

Phosphorus fractions in soil

The procedure of Chang and Jackson (1957) as modified by Peterson and Corey (1966) was followed for fractionation of soil phosphorus. The sequence of Saloid-P, Al-P, Fe-P, Occluded-P and Ca-P from each sample was passed through a 60-mesh sieve.
The soil extractant for various fractions in sequence were as follow: -

- Saloid-P extracted by 1 N NH_4Cl solution
- Al-P extracted by 0.5N NH_4F solution (buffered at pH 8.2)
- Fe-P extracted by 0.1 N NaOH solution
- Occluded-P extracted by 0.1N NaOH solution
- Ca-P extracted by 0.5 N H_2SO_4 solution

Statistical analysis of the experimented data

The data were statistically analysed and correlations amongst various parameters were computed as per standard procedure described by (Panse and Sukhatme, 1970).

RESULT AND DISCUSSION

Soil pH

The pH values ranged from 7.48 to 7.58, indicating that continuous cropping and fertilizer use did not have a significant adverse effect on the soil pH. This could be attributed to the high buffering capacity of the soil, as suggested by (Dwivedi and Dwivedi, 2015). The findings align with previous research by Raghuwanshi *et al*., (2016).

Over the course of 50th years of continuous fertilizer additions and intensive cropping, no significant alteration in soil pH was observed concerning depth. The soil's remarkable buffering capacity, as noted by Suman *et al*., (2017), allowed it to effectively maintain its pH levels despite these agricultural practices.

Soil EC

The initial soil electrical conductivity (EC) values, ranging from 0.15 to 0.20 dS/m, remained largely unchanged throughout the study. The application of various fertilizer and manure doses did not have a significant impact on the soil's EC in a Vertisol. Even the continuous use of synthetic fertilizers over an extended period did not noticeably alter the soil's EC. The combined use of farmyard manure (FYM) and fertilizers resulted in minimal changes, likely attributed to the addition of organic manure, which enhanced the soil's buffering capacity, as reported by Gupta *et al*., (2019).

After the 50th years of continuous fertilizer addition, the soil's electrical conductivity (EC) did not show significant changes concerning depth. These findings align with the research conducted by Panwar *et al*., (2017), Suman *et al*., (2018), and Khandagle *et al*., (2019). All these studies reported similar results, indicating no considerable alterations in soil EC due to the continuous application of fertilizers.

Soil organic carbon

The data showed that the lowest organic carbon content 4.68 g kg^{-1} was noted in control. However, the organic carbon content improved significantly with proportionate increment in fertilizer addition at 50% NPK (6.28 g kg^{-1}), 100% NPK (7. 27 g kg^{-1}) and 150% NPK (8.02 g kg^{-1}) doses. This finding appeared to be due to enhanced root development of crop resulting higher residues as a result of intensive farming with continuous fertilizer applications. These results are also in agreement with the finding of Parihar *et al*. (2010) and Patel *et al*., (2018).

The application of 100% NPK+FYM, there was a noticeably higher level of soil organic carbon (6.89 g kg^{-1}) reported by Birla *et al*., (2015) showed that organic manures (FYM) were discovered to be a practical option for improving soil organic carbon and nutrient turnover, thereby improving nutrient availability in the soil, maintaining soil quality, and achieving sustainable productivity. Similar results were also reported by Meshram *et al*., (2018) and Bagde *et al.,* (2023).

Table 4. Impact of long-term use of fertilizers and manure on soil properties in surface and sub surface soils

	Treatments	Soil pH		EC (dSm^{-1})		OC ($g\ kg^{-1}$)		Available N ($kg\ ha^{-1}$)		Available P ($kg\ ha^{-1}$)		Available K ($kg\ ha^{-1}$)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	50% NPK	7.50	7.62	0.15	0.16	6.28	4.86	226	197	19.97	19.37	260	250
T_2	100% NPK	7.55	7.63	0.17	0.18	7.27	5.83	292	220	33.64	30.12	302	286
T_3	150% NPK	7.58	7.66	0.20	0.21	8.02	6.94	331	280	36.72	34.18	326	310
T_4	100% NP	7.53	7.63	0.16	0.16	6.74	5.32	267	205	29.71	27.73	252	243
T_5	100% N	7.48	7.52	0.15	0.16	5.38	4.45	219	178	9.89	8.76	248	239
T_6	100% NPK + FYM	7.54	7.62	0.16	0.17	8.94	7.11	340	285	37.53	35.62	336	315
T_7	100% NPK – S	7.56	7.64	0.17	0.18	7.21	5.43	275	210	30.87	28.18	296	278
T_8	Control	7.51	7.56	0.15	0.16	4.68	4.01	190	160	8.91	8.03	244	237
	S.Em. ±	**0.048**	**0.036**	**0.015**	**0.014**	**0.28**	**0.24**	**8.96**	**7.59**	**0.76**	**0.69**	**8.24**	**8.68**
	C.D. (*p*=0.05)	**NS**	**NS**	**NS**	**NS**	**0.85**	**0.73**	**26.4**	**22.33**	**2.24**	**2.05**	**24.25**	**25.55**

NPK: The per cent amount of nitrogen, phosphorus and potassium applied through inorganic fertilizers.

*FYM (contains 0.53% N,0.30% P_2O_5 and 0.63 K_2O) was applied 5 t ha^{-1} to soybean every year 15-20 days before sowing;

#DAP was used instead of SSP as a source of P.

NS: Non-Significant

Fig.1 Impact long-term use of fertilizers and manure on available Nitrogen content in soil

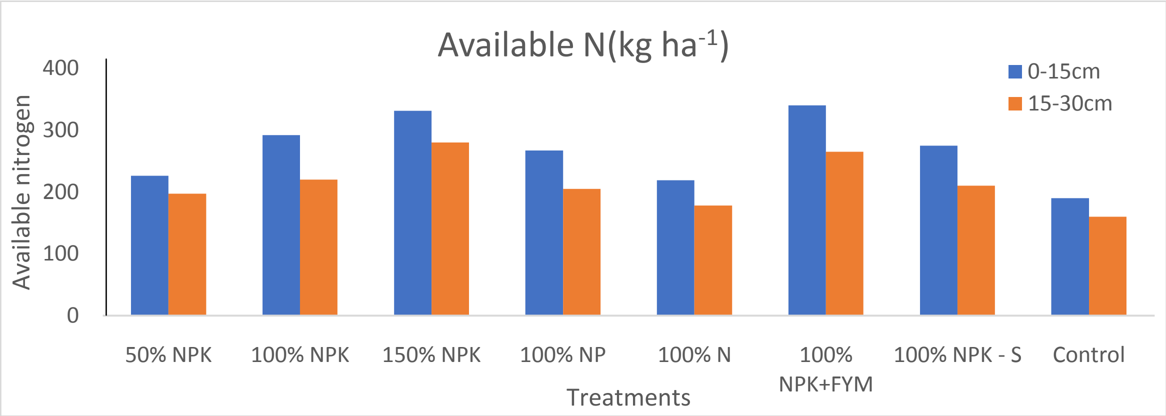


Fig.2 Impact of long-term use of fertilizers and manure on available phosphorus content in soil

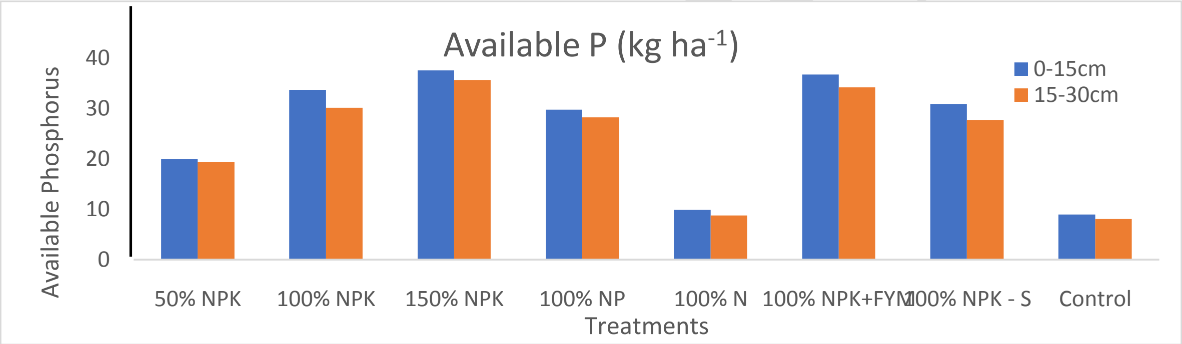
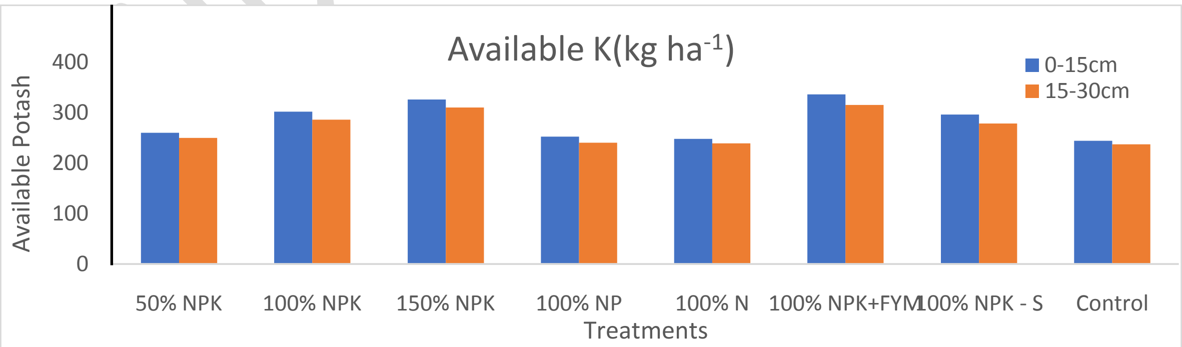


Fig. 3 Impact of long-term use of fertilizers and manure on available potash content in soil



Available nitrogen in soil

The highest value of available N at 0-15 cm depth of soil was recorded in 100% NPK+FYM (340 kg ha^{-1}) treatment. However, the lowest value of available N content was observed in control (190 kg ha^{-1}) followed by 100% N (219 kg ha^{-1}). The data presented in Table 4 and Fig. 1. indicated a decrease in the available nitrogen (N) content in the soil as the depth increased. The highest available N content, measuring 285 kg ha^{-1}, was recorded in the treatment with 100% NPK + FYM at a soil depth of 15-30 cm. Observations revealed that higher nitrogen levels were observed in the surface soil, which gradually decreased with depth. The rate of decline was more pronounced from the surface to the subsurface layers, as reported by Singh *et al*., (2013). This pattern could be explained by the presence of higher root biomass in the rhizospheric soil layer. Similar findings were also reported by Khandagle *et al*., (2020).

Available phosphorus in soil

The available P was changed from 8.91 kg ha-1 (control) to 19.97 kg ha-1, 33.64 kg ha-1, and 36.72 kg ha-1 in the 50% NPK, 100% NPK, and 150% NPK treatments, respectively, as shown in Table 4 and Fig. 2. Further, it was the highest with 100% NPK+FYM (37.53 kg ha^{-1}). while the lowest values were observed in the control plot (8.91 kg ha^{-1}), followed by the 100% N treatment (9.89 kg ha^{-1}). This indicates that higher doses of NPK fertilizers resulted in increased available P content in the 0-15 cm depth of soil. Similar results were reported by Dubey *et al*., (2015) and Birla *et al*., (2015). Moreover, the most elevated P content was observed in treatments involving the combined use of fertilizer and farmyard manure (FYM) at a rate of 36.72 kg ha^{-1}, highlighting the advantageous impact of FYM on P mineralization within the soil to a greater extent by Dwivedi *et al*., (2019). The data also accentuated that P accumulation was more pronounced near the soil surface compared to deeper layers. The long-term application of fertilizers increased the concentration and accumulation of P in shallower depths than in deeper soils reported by lu *et al*., (2020)

Available potassium in soil

The initial value in (1972) of available K was 370 kg ha^{-1}. The available potassium (K) content in the soil at the 0-15 cm depth showed a progressive increase with the successive addition of fertilizers, starting from 50% NPK (260 kg ha^{-1}), then 100% NPK (302 kg ha^{-1}), and 150% NPK (326 kg ha^{-1}) treatments, respectively (Table 4 and Fig. 3). Notably, the treatment that received 100% NPK along with farmyard manure (FYM) showed the highest available K content (336 kg ha^{-1}) among all treatments. On the other hand, the control plot had the minimum available K content (244 kg ha^{-1}), followed by the 100% N treatment (248 kg ha^{-1}) at the same depth. Reported that 100% NPK+FYM treatments followed by 150% NPK treatments were related to the greatest available K status in soil. Similar results were also reported by Patidar *et al*., (2021) and Pathariya *et al*., (2022) In addition to the direct addition to the soil's accessible K fractions, the application of organic manure may have decreased K fixation and consequently raised K content due to the interaction of organic matter with clay. Inwati *et al*., (2022) similarly reported comparable outcomes.

Phosphorus fractions in soil

The data associated with Phosphorus fractions (Saloid-P, Al-P, Fe-P, Occl-P, Ca-P) in soil are given in table 5

Saloid-P form

The effect of continuous cropping and fertilizer applications on content of Saloid-P form revealed that (table 5) the lower content was recorded in control (4.39 mg kg^{-1}) followed by 100% N (5.27 mg kg^{-1}) which could be because of the fact that without application of fertilizer and or without P inclusion in fertilizer schedule has obviously resulted in its lower content. On the other hand, successive additions of P from 50% NPK 100% NPK and 150% NPK resulted in proportionate increase in Saloid-P in soil. This might be due to proportionate higher transformation of P from both inherent and applied sources with soil system into Saloid-P as suggested by Badrinath *et al.,* (2005). Nonetheless, the most substantial content emerged when 100% NPK was administered alongside

FYM, underscoring the collaborative effect of organic manure in expediting the conversion rate into soil-resident Saloid-P, consequently rendering it available for subsequent uptake by cultivated plants.

A diminishing pattern in the Saloid-P configuration was noted as depth increased, with the greatest proportion of Saloid-P localized near the surface and gradually diminishing towards deeper soil layers. This phenomenon could be attributed to the limited mobility of Saloid-P, impeding its downward migration, as elucidated in studies by Dubey *et al.,* (2016) and Sudhakaran *et al*., (2018).

Aluminium bound Phosphorus (Al-P)

Application of increasing doses of fertilizer increased the content of Al-P form in the soil (table 5). While it declined when P addition was committed there by lower content was noted in control (9.02 mg kg^{-1}) and 100% N (12.42 mg kg^{-1}) due to absence of addition of P. Similar results were reported by Sood and Bhardwaj, *(*1992). In this regard, Fe-P and Al-P were found to be predominant in the surface soil horizon, according to Ganesh *et al*., (1993).

Al-P content exhibited a gradual decrease with increasing depth, with the most significant buildup observed at the surface. Corresponding outcomes were also documented in the study by Dubey *et al.,* (2016).

Iron bound phosphorus (Fe-P)

The data of Fe-P form was increased with successive higher P fertilizer application over without additions i.e., in control (19.17 mg kg^{-1}) and 100% N (20.08 mg kg^{-1}) which could be due to higher transformation of added fertilizer P in soil equilibrium to Fe-P retention in soil. It has also been noted that a significantly higher content of Fe-P was observed with successively higher addition of P from optimal to super optimal dose which might be due to the differential conversion of applied P in Fe-P form as a result of varying transformation (Sarkar *et al.,* 2014). In this regard, Fe-P and Al-P were found to be predominant in the surface soil horizon, according to Ganesh *et al*., (1993).

Elevated levels of Fe-P were observed near the surface, gradually decreasing as depth increased. This phenomenon may arise from the potential movement of both phosphorus and iron ions, particularly limiting their concentration in the lower layers. Comparable findings were documented by Badrinath *et al*., (2005).

Occluded phosphorus (Occl-P)

The data on content of Occl-P form (table 5) that intensive cropping with continuous use of fertilizer over 50th year has resulted in appreciable build-up of Occl-P form when increasing rates of fertilizer were applied over successive cropping while a declining trend was noted with the imbalance applications. Similar results have been noted by Tiwari *et al.,* (2019). It has seen that application of phosphatic fertilizers significantly increased occluded P fractions over control. Reported by Bincy *et al.,* (2023).

A decrease in the Occluded-P condition was observed as depth increased, with the greatest concentration occurring at the surface. This suggests that phosphorus remains relatively immobile within the soil's lower layers, as noted by Dubey *et al*., (2016).

Calcium bound phosphorus (Ca-P)

The result showed that successive addition of fertilizer containing P progressively increased the content of Ca-P form over without application in an intensified cropping for the last 50th years particularly in black soils (Table 5). It has also been observed amongst all inorganic forms, the content of Ca-P ranks highest which was an indication of the fact that Ca-P form contributed to the major source of P in black soil as reported by Roy *et al.,* (2016). Lower Ca-P content was associated in the control and 100% N treatments where P fertilizer was not included. These finding are also in agreement with Sudhakaran *et al.,* (2018). The application of 100%NPK along with FYM recorded significantly higher Ca-P during the incubation period. (Bincy *et al*., 2023)

Minor fluctuations in the Ca-P form were observed with changing depth. This occurrence may be attributed to the prevalence of calcium ions exhibiting high CEC, thereby promoting the substantial generation and development of Ca-P compounds. Comparable findings were documented in a study by Badrinath *et al*., (2005). Tran and N'dayegamiye (1995) conducted an experiment and showed that Long-term application of organic manure at a rate of 20 t ha^{-1} increased soil P_i forms and maintained P_o fraction.

Table 5. Impact of long-term use of fertilizers and manure on phosphorus fractions in surface and subsurface soils

	Treatment	Fractions of phosphorus mg kg^{-1}									
		Saloid-P		Al- P		Fe- P		Occluded-P		Ca- P	
		0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
T_1	50% NPK	12.55	10.40	23.97	21.27	31.28	25.94	8.25	6.46	110.76	101.94
T_2	100% NPK	16.86	13.64	32.06	27.25	47.18	37.57	11.09	8.34	141.98	133.92
T_3	150% NPK	18.20	15.58	36.48	31.97	54.39	44.32	13.67	10.24	188.06	179.07
T_4	100% NP	16.17	12.85	30.12	25.81	45.49	38.88	9.78	7.55	136.52	128.01
T_5	100% N	5.27	4.65	12.42	11.03	20.08	13.92	6.41	4.78	98.81	92.36
T_6	100% NPK + FYM	18.87	16.31	37.12	32.27	51.55	45.12	14.36	11.30	190.12	181.17
T_7	100% NPK – S	16.59	13.17	30.90	26.88	46.36	39.28	10.58	7.85	138.83	130.65
T_8	Control	4.39	3.18	9.02	7.26	19.17	11.86	5.02	3.49	95.06	91.35
	S.Em. ±	**0.81**	**0.76**	**0.97**	**0.51**	**2.63**	**2.63**	**0.35**	**0.38**	**7.62**	**7.04**
	C.D. (*p*=0.05)	**2.40**	**2.25**	**2.86**	**1.51**	**7.76**	**7.74**	**1.04**	**1.12**	**22.43**	**20.72**

NPK: The per cent amount of nitrogen, phosphorus and potassium applied through inorganic fertilizers.*FYM (contains 0.53% N,0.30% P_2O_5 and 0.63 K_2O) was applied 5 t ha^{-1} to soybean every year 15-20 days before sowing; #DAP was used instead of SSP as a source of P.

CONCLUSION

The findings from a long-term experiment on soybean crop cultivation showed that the continuous use of both inorganic fertilizers and organic manure (FYM) over a span of 50 years led to an increase in all phosphate (P) fractions in both the topsoil and subsoil. The application of a balanced nutrient combination (100% NPK) and the simultaneous use of FYM (100% NPK+FYM) enhanced the P content and its various forms in the soil. On the other hand, continuous cropping without any fertilization or an imbalanced use of nutrients (100% N alone) had detrimental effects on crop productivity, causing a significant reduction in different P fractions in both the topsoil and subsoil. The analysis of various P fractions revealed that the order of their contribution was Ca-P > Fe-P > Al-P > Occluded P > Saloid-P in both surface and sub-surface soils. As a result, the balanced application of fertilizers, with or without organic manure, not only maintained crop productivity but also improved the overall P balance over a 50-year period.

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