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Effect of INM practices on distribution of forms of phosphorus under different cropping systems: Review

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Abstract
Studying the soil phosphorus (P) fractions is critical for elucidating the processes underlying soil P accumulation in cropping systems and mitigating the risk of P loss to the environment. Long-term cultivation with various fertilizer treatments and cropping systems can have a significant effect on the availability of P as well as its fractionation. External application of phosphorus fertilizer to soils of intensive cropping systems also surpass the P requirements of crops, accumulating P in the soil in chemically stable and insoluble forms that may become available to plants in subsequent years. The relative solubility of inorganic soil P fractions determines how the liable pool is replenished when it is exhausted by plant P removal. The inclusion of inorganic fertilizers with organic manures improved the labile P pools by means of improving the soil organic content and nutrient availability under multiple cropping systems there by reduced the non-labile pools of phosphorus. However, partial substitution of inorganic fertilizer with organics resulted in a substantial increase in almost all P fractions in soil. Thus, knowledge of the various inorganic fractions of soil P and their distribution within the soil is critical for determining the long-term availability of P to crops and formulating sound fertilizer recommendations. This will benefit not only the bioavailability of soil P, but also the reduction of water contamination caused by runoff P.

Keywords: Integrated nutrient management, organic manures, phosphorus fractions, cropping systems

Introduction
Phosphorus is the tenth most abundant element in the earth's crust and its average content is nearly 0.12 per cent. In lithosphere, it always occurs in the pentavalent oxidation state. Phosphorus is an essential element for plant growth. Therefore, maintenance of adequate amount of soil phosphorus through application of inorganic and/ or organic phosphorus is critical for the sustainability of cropping systems. In plant, it is essential for photosynthesis, respiration, cellular functions, gene transfer, and root growth. It performs the main function in energy transformation, metabolic processes and structure of plants that cannot be performed by any other element. Nearly 200 phosphate minerals have been reported to occur in nature. The most important of all these minerals is the apatite group, of which flourapatites constitute the bulk of the commercial source of phosphates.

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 (Park *et al.* 2006) [55]. The total P content in agricultural crops generally ranges from 0.2-0.5 per cent.

Phosphorus, like any other plant nutrient is present in soil in two major components *i.e.* organic and inorganic. Indian soils usually contain 44 to 3580 mg kg^{-1} of total P and traces to 2160 mg kg^{-1} of organic P. Organic P, which is mainly confined to the surface layer, is mineralized in to inorganic forms.

Plants mainly depend on inorganic P forms for their P requirements. Inorganic phosphorus fractionations have been widely used to interpret native inorganic P status and the applied P to soils. It has been established that saloid-P, Al-P, Fe-P and Ca-P fractions are the main sources of P supply to the plants (Mishra, 1994 [39], Singh *et al.,* 2014 [69]).

Knowledge on amount of each fraction and their relationship with soil characteristics is very useful in assessing phosphorus nutrition of plants. Since various P fractions and their contribution to available phosphorus provide useful information in assessing the availability in soil. Available P content increases with the application of P which is a function of certain physical and chemical properties of soil such as clay, organic carbon, Fe, Al and calcium carbonate contents. Marked variation in the different forms of inorganic P is a function of genetic differences among soils (Chang and Jackson, 1958) [13]. Organic matter, calcium carbonate and sesquioxides appear to be guiding factors in determining the distribution of forms of P (Brady and Weil, 2002) [11].

The dynamics of different P fractions in soils are poorly understood because there is no universally accepted fractionation. One approach to examine the availability of soil P is the use of chemical extraction procedures to fractionate P according to its solubility in specific reactants, which are assumed to approximate to the bio-available P pools (Chen *et al*., 2000) [14]. Information's of phosphorus fractions are important for evaluation of their status in soil and understanding of soil chemistry that influence soil fertility.

Phosphorus use efficiency in agricultural systems is very low, with only 10-20% of fertilizer P used by crops (Johnston and Syers, 2009) [26]). Typically fertilizer P is converted to less soluble forms due to reactions with aluminum (Al) and/or iron (Fe) in acid soils and with calcium in neutral to alkaline soils (Soffe 2003 [70]; Mitran*et al.*, 2016 [40]), which are usually insoluble under aerobic or upland condition (De-Datta, 1981) [15]. It is, therefore, very important to know the distribution of P fractions in soil in order to understand the repositioning mechanisms.

Plant species possess various strategies for acquiring soil P from soil-P pools. Legumes often release protons into the rhizosphere due to an excess uptake of cations over anions when fixing N_2 (Tang *et al.*1998) [77], which may mobilize less soil P, resulting in improved P nutrition and increased growth of the subsequent crops (Nuruzzaman *et al.*, 2005) [49].

Materials and Methods

The available phosphorus was extracted by using Olsen's extractant (0.5 M $NaHCO_3$ of pH 8.5) as described by Olsen *et al*. (1954) [53] and the phosphorus content in the extract was determined by Murphy and Riley (1962) [44] method using ascorbic acid as the reducing agent using spectrophotometer. The inorganic phosphorus fractions *viz*., solid-P, Fe-P, Al-P and Ca-P were estimated by following the sequential extraction procedure as given by Kovar and Pierzynski (2009) [29]. Total phosphorus in the soils was determined by perchloric acid digestion method as described by Jackson (1973) [23].

Different forms of P

Available Phosphorus

Amount of Olsen's-P decreased with increasing depth might be due to decreasing trend of organic carbon in the profile (Trivedi*et al*. 2010) [81]. Dutta and Mukhopadhyay (2007) [18] reported that in acidic soils the available P content highest in Binnaguri soil series while lowest in Kalajhariya soil comparatively lower clay content than that of the later. Pot culture experiment on rice revealed that on submergence increased in available P_2O_5 content of the soil at different intervals of crop growth and there was a significant difference in the available P_2O_5 content of soil treated with compacted fertilizers containing MAP and MAP+S over other treatments (Ravi *et al*., 2002) [58]. Integrated use of 50% PK from inorganic fertilizers and 50% from FYM resulted highest available P content in soil over other treatments in potato-radish cropping sequence (Jatav*et al.*, 2010) [25]. Hemalatha*et al.* (2011) [21] conducted a long term field experiment on different doses of graded fertilizers with and without FYM under finger millet-maize cropping sequence in TNAU, Coimbatore, and observed that the availability of P is higher in the plots receiving 100% NPK+FYM when compared with all other treatments. In a long-term field experiment on pearl millet-wheat cropping sequence at Soil Research Farm, CCSHAU, Hisar, Haryana, revealed that continuous application of different phosphatic fertilizers increased Olsen's available P in soil. The maximum increase of available P was found with DAP (18 ppm) and minimum with Rock phosphate (6.7ppm). The available P content of the soil in control decreased from its original level of 6.6 ppm to 2.7 ppm. In a long term fertilizer experiment on rice-rice cropping system at RARS, Jagtial, the results revealed that highest P build up in 150% NPK (116%) followed by 100% NPK+FYM (112%) when compared to all other treatments (Srilatha *et al*., 2015) [73]. Yamini*et al.* (2015) [85] observed that in groundnut mono-cropping the available P content was highest before sowing of the crop and slightly decreased at harvest in all the treatments. Available P content was highest in NPK +Gypsum +$ZnSO_4$ treatment compared to other treatments at both stages of crop. Sudhakaran *et al.* (2018) [75] observed that higher available phosphorus in Sorghum-Wheat sequence of 32 year long-term integrated nutrient management with integration of chemical fertilizer and FYM.

Inorganic P Fractions

Added water soluble P is usually converted to Al-P, Fe-P and Ca-P and the magnitude of this conversion depends upon the nature of soil and the time of contact of applied fertilizer with soil. In acid soils the dominant fractions were Al-P and Fe-P and in calcareous soils, Ca-P was the dominant form and increased contact period of submergence resulted in an increase in Fe-P at the expense of Ca-P (Mahapatra and patrck 1971) [35].

Mandal and Mandal (1973) [37] reported that in calcareous soil inorganic-P fractions was in the order of Ca-P > occluded Fe-P > Fe-P >Al-P > occluded Al-P. Jain and Sarkar (1979) [24] evaluated the conversion of added P into different forms of inorganic P in a sandy loam soil and reported that 57 percent of the added P was transformed into saloid-P and Al-P under aerobic conditions and it changed to Ca-P with time. Venkat Reddy *et al*. (1983) [82] reported that saloid-P, Al-P and Fe-P improved significantly with the increase in levels of phosphorus and FYM in soils of Tarai region of UP. Nad and Goswami (1984) [46] reported that about 62.5 per cent of added P got converted to Ca-P, 16 per cent to Fe-P and 13.1 per cent to Al-P due to continuous P fertilization under rice-wheat cropping system.

Patel *et al.* (1992) [56] studied the effect of phosphorus and organic matter on phosphorus fractions and observed that the application of P at (0, 50 and 100 ppm) all the levels significantly increased various P fractions over its no application. Agarwal *et al.* (1987) [2] in an experiment oninorganic soil phosphorus fractions and available phosphorus affected by long term fertilization and cropping pattern reported increased the saloid–P, Al-P, Fe-P, reductant soluble P, and available phosphorus status of the soil over the control due to the application of NPK 120:60:40 dose.More and Agale (1993) [42] studied the transformation of applied phosphorus. They observed that maximum applied P as superphosphate was transformed in to inorganic P fractions such as Al-P, Fe-P, Ca-P, R-P followed by diammoniumphosphate and suphala plus superphosphate. There was continuous increase in P fractions with increasing levels of phosphorus. Maximum of applied P as superphosphate was found to transform into inorganic P fractions (Al-P, Fe-P and Ca-P) followed by DAP and suphala + superphosphate at square formation, flowering and harvest stages of cotton (More and Agale, 1993) [42].

It was reported by Zhang *et al.* (1994) [88] that immediately after the application of organic manure, a large part of labile and moderately labile organic P supplied with the manure was transformed into moderately resistant organic P, possibly Ca or Mg- inositol phosphate were transformed into Fe-inositol phosphate. A study conducted by Richards *et al.* (1995) [59] to observe changes in forms and distribution of phosphorus indicated significant increase in resin Pi, $NaHCO_3$-Pi, and NaOH-Pi with 10 years of P fertilizer applications for continuous corn production in southern Ontario, Canada.

Tran and Ndayegamiye (1995) [80] studied the long term effect of manures and fertilizers on the forms and availability of soil phosphorus. They reported that application of manure and fertilizers increased significantly resin-$NaHCO_3$, NaOH-Pi (inorganic P) and Po (organic). However, NaOH-Po was decreased by P fertilizer application in NPK and NPK+Mg treatments, while long-term manure application maintained this Po pool in the soil. Stable P fractions were not affected by fertilization or by manuring. The field experiment on ten soils (eight alkaline and two acidic) conducted by Bahl and Singh (1997) [8] to study the influence of green manuring on inorganic phosphorus fractions. They found that saloid bound P increased while Fe-P, Ca-P and Al-P decreased significantly with the application of green manure in all the soils. The saloid bound P increased by 27 per cent in alkaline soil and 21 per cent in acidic soil at the expense of other three fractions.The changes in different forms of phosphorus in an acid soil due to long term manuring and fertilization were observed that the amount of Fe-P, Al-P and Sa-P increased with increasing dose of added phosphate (Prasad and Mathur, 1997) [57].

Bhakare and Sonar (1998) [9] revealed that application of increased levels of phosphorus resulted in increased values of forms of phosphorus in soil after soybean-wheat cropping sequence. Ca-P was found to be the most dominant fraction and increased from 321 to 392 mg kg^{-1} followed by reductant soluble P and least fraction was saloid P due to root proliferation and defoliation of biomass in soybean. On TypicUstocrept soil of Delhi, among the inorganic P fractions, saloid bound P constituted less than one percent of the total P and significant increase in saloid P as a result of fertilizer addition, could be attributed to the transformations of applied P into saloid P and Al-P under aerobic conditions in the first instance and then to Ca-P with time. Concentration of Al-P was greater than saloid-P but was relatively lower as compared to Ca-P due to calcareous nature of experiment soil. The Ca-P accounted nearly 62 percent of the total inorganic P (Singh *et al.*, 1998) [67]. Nziguheba *et al.* (1998) [51] studied the soil phosphorus fractions as affected by organic and inorganic sources. They reported that application of tithonia either alone or with TSP increased resin P, bicarbonate P, microbial P and sodium hydroxide inorganic P.

Kumar *et al.* (1999) [30] studied the effect of green manuring on phosphorus transformation from rock phosphate in an acid soil. They reported that all forms of inorganic P fractions increased with the increase in the P levels. Increase was more in green manure amended soil than in the soil incubated without green manure. In Typic Haplustert soils of Jabalpur, Tembhare and Kaushal (2000) [79] noted that inorganic P fraction at the inception of experiment were found to be in decreasing order as Ca-P, Fe-P, Al-P, saloid P and occl-P in the treatment where optimal and super optimal NPK dose were applied. The inorganic P fractions increased over a period of 20 years, indicating the transformation of applied P into all the P fractions

Sharma and Verma (2000) [63] found that the addition of lantana over six years increased Al-P, Ca-P and Red-P by 36, 29 and 9 per cent, respectively in the soil over control. Total inorganic-P fraction ranged from 312 to 366 mg P kg^{-1} soil and constituted 71 per cent of the total P in soil. Ammal *et al.* (2001) [5] studied the effect of different level of rock phosphate and sulfur granule on nutrient availability. They observed that the P fractions (NaCI TEA- P, NaOH-Pi) were increased at 60 kg level, but other fractions (NaOH-Po, HCI-P and residual P) were increased at 75 kg Pha^{-1}. Pandian and Jothimani (2001) [54] observed that application of recommended level of P at 60 kg P_2O_5 ha^{-1}maintained higher Ca-P, Fe-P and Al-P as compared to other levels. The amount of inorganic P varied significantly and the distribution of added P into different fractions was in the order of Ca-P > Fe-P > Al-P.

Murthy *et al.* (2002) [51] revealed that applied phosphate transformed mostly into Ca-P followed by Fe-P, Al-P and in general increased with increasing rates of phosphorus application in all the pedon irrespective of their parentage. Scherer and Sharma (2002) [61] studied the fate of P applied through different organic materials, (farmyard manure, compost and sewage sludge) in comparison to mineral fertilizer after 40 years of field experiment. The total P (Pt) content of all treatments increased compared with the original P in the soil; NaOH-inorganic P (NaOH-Pi) representing Fe- and Al-bound P was the dominant inorganic fraction. At the beginning of the experiment the various P pools could be quantitatively ranked in the following order: NaOH-Pi > residual P~$NaHCO_3$-Pi> H_2O-P>HCl-P. The order changed to NaOH-Pi>$NaHCO_3$-Pi>residual P~H_2O- P>HCl-P, with transformations of non-labile residual P to the labile NaHCO3-Pi pool with continued P fertilization and cropping. Motavalli and Miles (2002) [43] studied the phosphorus fractions after 11 years of manure and fertilizer application. They reported that long-term application of fertilizer and manure significantly increased NaOH-extractable Pi, a more slowly available P fraction than resin Pi and $NaHCO_3$-Pi.Continuous fertilizer application and rice cultivation led to a decrease in ratio of organic P to total P in the plow layer with the lapse of time. The combined application of chemical fertilizers and compost accelerated the decrease in the organic P fractions, presumably due to the promotion of microbial activity in the plow layer, even though a high amount of organic P was added through compost.

Moderately labile organic P (MLOP) was the main organic P compound in this paddy soil, which accounted for 70- 90 per cent of organic P and showed the same tendency as that of the total organic P fraction (Lee *et al.*, 2004) [34]. The experiment on long term effect of compost and fertilizer on phosphorus fractions conducted by Park *et al.* (2006) [55] revealed that application of compost, chemical fertilizers or both significantly increased Fe-P and Al-P in comparison to the control treatment, but Ca-P content was not much influenced. In the treatments receiving chemical P fertilizer, Fe-P and Al-P contents were significantly increased in comparison to the control and compost treatments. According to Zhang (2004) [87], the increased P rates favoured soil P transformation from (labile inorganic P) LPi to (moderately labile inorganic P) MLPi.

Akhtar *et al.* (2005) [3] studied the effects of manure application on phosphorus fractions. They observed that all P fractions were higher in 0-7.5 cm depth than any other amended soil depth. According to Sihag *et al.* (2005) [66] who conducted experiment on the effect of integrated use of organic and inorganic fertilizers on different forms of phosphorus in soil, they reported that amount of P recovered in saloid-P, Al-P and Ca-P form increased significantly with the application of inorganic fertilizers and their combined use with organic materials over control. The highest amount of all the forms of P was recorded under farmyard manure followed by green manuring and press mud treatments. Averaged across treatments, saloid-P constituted about 2 per cent of the total P.Duminda *et al.* (2005) [17] found that, in the soil depth of (0-25) cm, the ability of different fertilizers in producing plant available P, Sa-P and Al-P vary in the order of TSP > IRP > ERP. Further, it was noted that, the availability of Sa- P and Al-P in the TSP treated soil increased with increasing level of TSP application to the soil. The different P fractions in the TSP treated soil were in the order of Sa-P >Al-P >Occ-P > Fe-P >Ca-P. The effect of organic and inorganic amendments on phosphorus fractions in soils was studied by Shil *et al.* (2005) [64]. They observed that solution-P, labile-P and inorganic-P fractions increased significantly due to use of organic amendments but triple superphosphate did not increase these fractions significantly.

Kolawole and Tian (2007) [28] reported that when phosphate rock was combined with plant residues, there was increase in almost all the P fractions. The findings of the experiment on the effect of rock phosphate, superphosphate and their mixtures with FYM on soil phosphorus pools conducted by Majumder *et al.* (2007) [36] indicated that rock phosphate, superphosphate along with their mixtures with FYM resulted significant increase in saloid-P, Al-P, Fe-P and Ca-P fractions. Djuniwati *et al.* (2007) [16] studied the effect of rock phosphate and organic matter on P fractions. They observed that application of rock phosphate and organic matter increased inorganic phosphorus fractions. The experiment on phosphorus dynamic during wheat growth on a continous maize-wheat cropping system indicated that application of P increased all the P fractions irrespective of the growth stage of the crop (Setia and Sharma, 2007) [62].

The effect of rock phosphate and triple superphosphate (TSP) on soil P fractions was studied by Rivaie*et al.* (2008) [60]. They observed that the rate of increase of the P fractions was highest for NaOH-Pi when TSP was applied and highest for H_2SO_4-Pi when a phosphate rock (BGPR, origin Ben Guerir, Morocco) was applied. The largest pool of soil P, the NaOH-Po (labile organic P), was unaffected by the applications of these P fertilizers. Tang and Armstrong (2008) [78] observed that increasing long-term P application rate over 65 years significantly increased all inorganic P (Pi) fractions except HCl-Pi. Increasing P application also increased Olsen-P decreased the P buffering capacity and sorption maxima. Residual P, Pi (inorganic P) and Po (organic P) fractions accounted for an average of 32, 16 and 52 per cent of total P, respectively. According to Galvani (2008) [19] who conducted experiment on the effect of phosphorus sources on soil P fractions, the phosphorus content increased down to 40 cm depth after the soybean crop and the increase was observed mainly in Ca-bound P and organic phosphorus. However, there was a decrease in Fe-bound P, showing that P availability to soybeans was related to this fraction.

Boschetti *et al.* (2009) [10] studied phosphorus fractions of soil as effected by different phosphorus fertilizers. They observed that the addition of different P fertilizers increased P levels in all the inorganic fractions at sowing with the exception of the residual fraction. Nwoke *et al.* (2009) [50] observed the effect of phosphate rock on soil phosphorus fractions and reported that application of 90-PR (phosphate rock) and 30-SSP (single superphosphate) resulted in similar increase in available P but the effects of 90-PR on the Ca-bound pool were significantly higher than those of 30-SSP. A field experiment to investigate the role of organic and inorganic sources of phosphorus on different fractions of phosphorus was conducted by Jatav *et al.* (2010) [25] and revealed that significant increase in saloid-P, AI-P and Ca-P and decrease in Fe-P under integrated use of inorganic fertilizers and FYM.

The use of phosphorus fertilizer in combination with N and K raised the soil P content in all the fractions such as saloid P, Al-P, Fe-P, Ca-P and total P in soil. The increase was more at higher rates of P addition along with higher doses of N and K compared to differential combinations of N, P and K (Singh *et al.*, 2010) [68]. Inorganic phosphorus fractions as affected by fertilization were studied by Huang *et al.* (2011) [22] and observed that Ca-P, Al-P, Fe-P decreased in absence of P application whereas these fractions increased with P supplementation. An experiment conducted by Lan *et al.* (2011) [32] who studied the effect of long term fertilization on P fractions indicated that most of the soil inorganic P fraction increased with time by combined application of organic and inorganic fertilizers. In acid soils of Meghalaya, Laxminarayana (2011) [33] reported that Fe-P was the major P fraction contributing to the available P pool as extracted by different extraction methods as well as P nutrition of rice. Vu *et al.* (2011) [80] studied the long term changes in P fractions after fertilization. They observed that the NaOH-Pi was the dominant P fraction in the Chromosol and Ferrosol where it increased markedly in these soils following long term P application. In comparison, H_2SO_4- Pi was a major pool in the Vertisol, the Calcarosol and Sodosol soils, and tended to be larger in the cultivated soils compared to the respective reference soils. Abolfazli *et al.* (2012) [1] conducted experiment to evaluate effects of phosphorous fertilizer (PFs) from sources of triple superphosphate (TSP) and di-ammonium phosphate (DAP) and organic fertilizers (OFs) from sources of cow dung manure (CDM) and municipal solid waste compost (MSWC) on phosphorous (P) fractions including aluminium- P (Al-P), iron-P (Fe-P), reductant soluble-P (RS-P), calcium-P (Ca-P) and available- P (Olsen-P) fractions under rice cultivation carried out in calcareous and acidic soils. They found that Ca-P was the predominant form of P in calcareous soil while Fe-P and Al-P in acidic soils. In calcareous soil, all forms of P under submerged conditions had been increased because of using PFs both alone and in combination with OFs. In acidic soil, significant amounts of P fractions were found only in Fe-P and RS-P fractions.

Rock phosphate enriched biogas slurry, press mud and farmyard manure alone and in combination with DAP in different ratios (1:3, 1:1 and 3:1) were evaluated in field with soybean-wheat cropping sequence at the IARI, New Delhi on a sandy loam soil and found that application of manure showed significant increase in available P over control. Among the fractions of phosphorus Fe-P, Ca-P and organic P fractions in soil remained almost unaltered while saloid-P and Al-P fractions were increased in comparison to their initial concentration noted before sowing the soybean. The extent of increase was more at higher rates of P application to soybean. Application of rock phosphate enriched biogas slurry in the ratio of 1:1 and 3:1 of DAP and manure on P_2O_5 basis gave the highest increase in the P fractions of soil (Kumar *et al*., 2013) [31]. Subbaiah *et al*. (2013) [74] conducted a field experiment in *kharif* (Maize) reported that highest P fractions *viz.*,saloid P, Al-P, Fe-P and Ca-P (6.8, 59.1, 72.3 and 120.2 mg kg $^{-1}$) were observed with application of 75% P through RDF + 25% P through VC + PSB. Yin and Liang (2013) [86] studied the transformation of phosphorus fractions in paddy soil amended with pig manure and concluded that the application of organic fertilizer could increase the content of the phosphorus fractions of paddy soil.

Meena and Biswas (2014) [38] conducted an experiment in a wheat – soybean cropping system and reported that application of 5 t ha^{-1} enriched compost with *Aspergillus* along with 50% RDF resulted in increased concentration of saloid-P, Fe-P, Al-P, Ca-P and Total-P (23.6, 34.1, 34.2, 244.4 and 571 mg kg^{-1}) over no fertilizer (9.8, 13.8, 21.7, 149.5 and 495 mg kg^{-1}). Effect of phosphorus levels on yield and fractions of phosphorus revealed that Sal-P (8.73 mg kg^{-1}), Ca-P (197.509 mg kg^{-1}) and total-P (623.19 mg kg^{-1})were more when 90 kg P_2O_5 was added while the significant increase in Al-P and Fe-P were recorded with increasing level of P up to 30 kg P_2O_5 (35.58 &39.44 mg kg^{-}1,respectively) and its concentration was decreased thereafter according to Shubhangi *et al*. (2014) [65].

Nayak*et al*. (2015) [48] observed that all P fractions were higher in surface layer than that subsurface layer. The sequential order of dominance of different forms of P were Ca-P > Red- P > Fe-P > Al-P >saloid. The highest value of P fractions were recorded in the treatments 150 per cent NPK and 100 per cent NPK+FYM in vertisol under rice crop. Ojo *et al*. (2015) [52] they was reported buildup of organic P was observed when poultry manure was applied at 15 t ha^{-1}while the combination of the poultry manure with SSP increased residual P and Fe-P. However, P occlusion was effectively reduced with the sole application of poultry manure. Kaur *et al*. (2015) [27] found that there was an improvement in inorganic P fractions under integrated fertilizer treatments compared to inorganic fertilization in rice-wheat cropping system. The potential of maximum P was bounded in Ca-P followed by Al-P> Fe-P> Sa-P fractions. All the four P fractions had significantly higher value under 100%NPK+FYM as compared to 100%NPK treatment. Sukhvir*et al*. (2015) [76] observed that application of integrated fertilizers recorded significantly higher Sa-P compared to inorganic treated plots and control. Among the integrated fertilizers application, highest Sa-P, Al-P, Fe-P and Ca-P concentration were under 100%NPK+FYM (21.4, 90.8, 46.5 and 316.8 mg kg^{-1}) followed by100%NPK+GM (20.8, 89.4, 40.7 and 298.7 mg kg^{-1}, respectively) under rice-wheat cropping system in loamy sand soils of Punjab. However the difference was significant for all fractions except Sa-P.

The changes in P pools over three months in two soils amended with legume residues compared to the unamended control, addition of faba bean and chickpea residues increased the concentrations of resin P, microbial P, $NaHCO_3$-Pi temporarily whereas amendment with white lupin residues had little effect on P poolconcentrations. The decrease in $NaHCO_3$-Po and NaOH-Po towards the end of the experiment coincided with an increase in NaOH-Pi (Alamgir and Marschner, 2016) [4]. Nayak and Patel (2016) [47] revealed the effect of fertilization on soil phosphorus and its fraction in soil that concentrations of soil Pi fractions after long-term fertilizer P applications at the Changwu Agro-ecological Experimental Station, were significantly increased in treatment applied with 79 kg P ha^{-1} than control.

Amruth*et al*. (2017) [6] conducted experiment on effect of phosphorus levels through Integrated Nutrient Management (INM) packages on phosphorus availability and phosphorus fractions in soil under groundnut crop at College of Agriculture, Shivamogga during *kharif*2015-2016 in sandy loam soil and found that significantly higher amount of all inorganic and organic forms of P in soil were recorded in application of higher dose of P i.e.50 kg ha^{-1}. Among the percent contribution of different phosphorus fractions *viz.*, saloid-P Al-P, Fe-P, reductant Soluble-P, occluded- P, Ca-P, organic-P to total-P, the lowest contribution to total-P from occl-P (3.20%), Ca-P (3.46%), followed by saloid-P (6.16%), red-P (9.83%). The contribution from org-P (51.96%) to total-P found to be highest, but Al-P (13.73%) and Fe-P (13.16%) was observed to be similar per cent contribution to total-P.

Anjali and Dhananjaya (2017) [7] revealed that the higher values of saloid –P and Ca –treatment. Similarly higher values of Al- P, Fe -P, red -P, occl- P, organic - P and total - P fractions were recorded in treatments involving P levels without PSB seed treatment compared to application of P levels with PSB seed treatment. The treatment which received 50 kg P_2O_5 ha^{-1} as DAP recorded higher Al- P, Fe- P, red- P, occl- P, organic- P and total - P values at all the growth stages of groundnut on a sandy loam soil. Chandrakala *et al*. (2017) [12] studied the relationship between addition, fixation and distribution of P fractions and reported a positive correlation of P-buildup in gradient strips with levels of P application in finger millet- maize cropping system as well as the increased total-P, organic-P, occluded-P and Ca-P fractions were observed as the soil phosphorus content increased.It was reported by Song *et al*. (2017) [71] that, the values of the inorganic P (Pi) fractionation, including Ca-P, Al-P and Fe-P, significantly increased over time by310.89 mg·kg^{-1}, 36.21 mg·kg^{-1}, and 18.77 mg·kg^{-1}, respectively, with organic matter (OM) treatment and by 86.92 mg·kg^{-1}, 175.87 mg·kg^{-1}, and 24.27 mg·kg^{-1} with chemical fertilizer (CF) treatment. Soremi *et al*. (2017) [72] found that residual P, redundant soluble P and occluded P had highest values of the inorganic P in the first planting season while application of poultry manure reduced P fixation, residual P and occluded P fractions in the soil in the second season. Venugopal *et al*. (2017) [83] from their results using sorghum as test crop observed that application of FYM along with NPK resulted in higher phosphorus fractions saloid P (9.6 mg kg^{-1}), Al-P (13.8 mg kg^{-}1), Fe-P (30.4 mg kg^{-1}), occluded P (5.4 mg kg^{-1}), Ca-P (40.4 mg kg^{-1}) and total P

(155.2 mg kg^{-1}) than application of only NPK under long term fertilization and manuring. Monika *et al*. (2018) [41] reported that Fe-P and Reduct-P had negative significant relation with silt while Ca-P had significant positive correlation. Saloid–P, Al-P, reduct-P, org-P and total-P had significant positive correlation with clay.

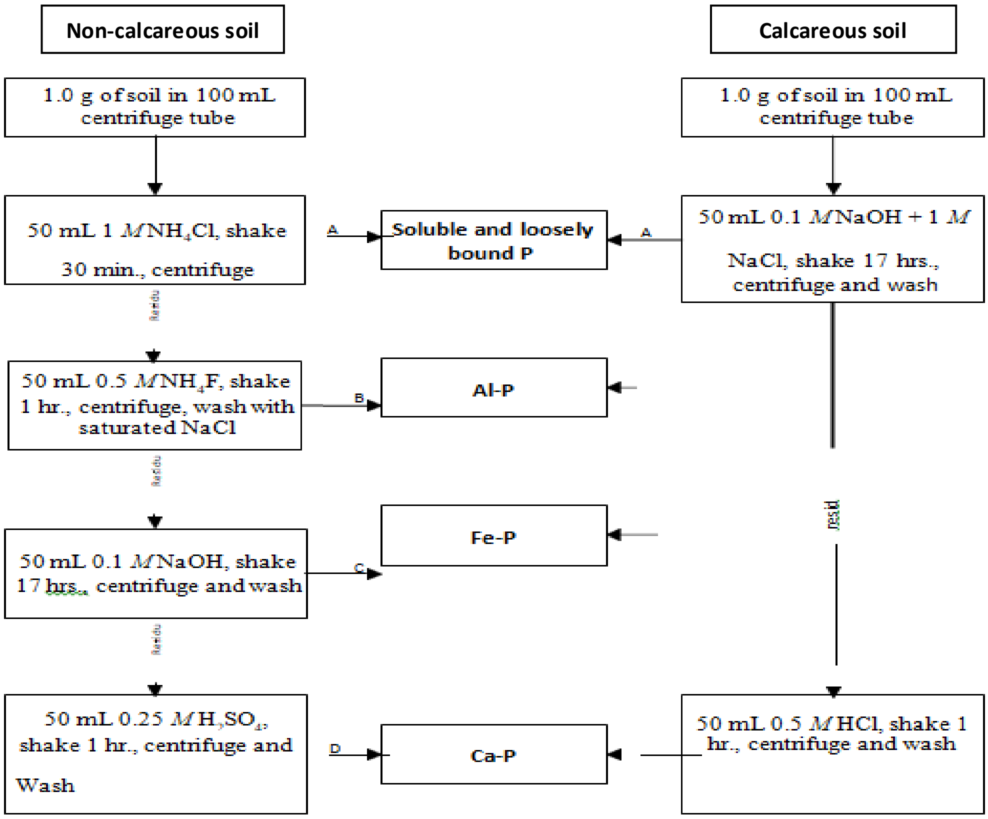

Fig 1: Sequential fractionation scheme for inorganic Pas given by Kovar and Pierzynski (2009)

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