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**Rashmi Priyadarshi**
Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

**Santosh Kumar**
Regional Research Station, Agwanpur, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

**CD Choudhary**
Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

**Correspondence**
**Santosh Kumar**
Regional Research Station, Agwanpur, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

# Phosphorus fraction dynamics in soil as affected by tillage and cropping system under irrigated agro-ecosystem

**Rashmi Priyadarshi, Santosh Kumar and CD Choudhary**

**Abstract**
Three prevalent cropping systems with different tillage practices were tested in factorial randomized block design, each replicated thrice at two depths *i.e.* 0-15&15-30 cm to evaluate their impact on availability of different fractions of phosphorus in soil. Three treatments in main plot for tillage practices were: Zero tillage (ZT), Permanent Bed (PB) and Conventional tillage (CT) and three treatments in sub plot for cropping system were: Rice-Wheat (R-W), Maize-Wheat (M-W) and Maize-Maize (M-M). The results shows that tillage and cropping system had significant impact on the Iron, Aluminium and calcium bound phosphorus content in surface (0-15 cm) and sub-surface soil (15-30 cm) soil. The highest Iron and Aluminium bound phosphorus was found in zero tillage system (ZT) followed by Permanent bed (PB) and conventional tillage (CT) system at both surface and sub-surface soils. Whereas, Rice-Wheat (R-W) system shows highest Iron, Aluminium and calcium phosphorus content followed by Maize- Wheat system and Maize-Maize system. Residual phosphorus at surface level, the maximum was observed in ZT fallowed by PB and CT system. However, at sub surface permanent bed showed higher residual phosphorus fallowed by ZT and CT.

**Keywords:** bond phosphorus, residual, phosphorus fraction, tillage

## Introduction

Soil being an essential resource to biosphere and human beings, is also amongst the most complex and least understood systems. Plant acquires phosphorus from soil solution as orthophosphate anion. A large proportion of total P in the soils of the area is unavailable to plants and consequently P is the second most limiting nutrient. Naturally occurring P in arable soil depend on weathering, deposition, sedimentation, and erosion processes, but also on soil variables such as organic matter (OM), oxides, Ca carbonate, and clays. However, normal agricultural practices generally cause enrichment of P (McDowell *et. al*., 2001) [15]. Soil P contents of intensively managed agricultural soils have increased in many parts of the world, where P input from fertilizer, manure, and sewage sludge exceeds the withdrawal of P by harvested crops (Jalali, 2007) [11].

The distribution of P within different fractions provides an indication of the potential stability of P in soil which may differ between land uses. Castillo and Wright (2008) [3] studied soil P pools for histosols under sugarcane and pasture in the Everglades, USA. They found that long-term fertilization increased soil total P for cultivated soil relative to pasture, but plant available P constitutes < 1% of total P. They indicated that most of the applied P was recovered in the Fe-Al fraction for pasture and the Ca-bound P fraction for cultivated soil. They indicated that the Ca-bound P fraction represented the greatest proportion of total P for sugarcane (41%), but only12% for pasture. The distribution of P among soil chemical fractions differed between land uses, with the highest storage in the Ca-bound fraction for potato and garlic but in the Res-P fraction for pasture. Long-term fertilization increased P retention in mineralassociated fractions, particularly the Ca-bound fraction. Tillage and cultivation decreased organic P, and the incorporation of Ca into soils by irrigation water enhanced P sequestration in the Ca-bound fraction.

Continuation of conventional crop management practices will likely further increase soil Ca levels, leading to greater recovery of P fertilizer in the Ca-bound fraction and lower P availability to plants. Mohsen *et. al.*, (2011) [16]. Phosphorus in soil is considered to be distributed among several geochemical forms that include soil solution and exchangeable phase, OM phase, Ca-bound phase, and Fe and Al-bound phases (Hedley *et. al.*, 1982) [7]. The degree of P association with different geochemical forms strongly depends upon phyisico-chemical properties of the soils due to soil type (Tiessen *et. al.*, 1984) [23], climate, and management practices (Motavalli and Miles, 2002) [18]. These P fractions have remarkable differences in mobility, bioavailability, and chemical behavior in soil and can be transformed under certain conditions (Sharpley *et. al*., 2000) [20]. It is least mobile element in plants and soil contrary to other macronutrients. Strongly weathered soils absorb large amounts of phosphorus (P) and limit plant growth as a result (Vitousek *et. al.*, 2010) [24]. The degree of interaction between phosphate and soil minerals can be measured via the maximum phosphorus adsorption capacity or remaining phosphorus. The low levels of plant-available P often encountered in some soils of the eastern part of India present major problems to crop production. Most of these soils are characterized by low activity clays containing crystalline, low specific surface minerals (*e.g.*, kaoline) as well as the oxides and hydroxides of Fe and Al (Mokwunye, 1979) [17]. These and other soil factors such as exchangeable cations and pH of the system, contribute to the removal of available P from the soil solution (Brennan *et. al*., 1994) [2]

Changes in farm management practices may be required to speed up the rates of soil P decline without impairing farm productivity. One possible solution is the use of conventional tillage to redistribute P within the plough layer during the reseeding of grazed pastures. The main driver towards conservation tillage is a decrease in soil erosion (Logan *et. al*., 1991) [14]. However, maintaining P fertiliser applications without periodic mixing within the plough layer (conventional tillage) can lead to P accumulation in the surface soil and stratification within the soil profile. The ability of soil to retain nutrients is increased by addition of organic materials and this play a major role in reducing soil erosion and maintaining long term soil health and productivity.

Improved nutrient management and soil conservation practices are gaining importance in research and policy communities (Khan *et al.*, 2007) [12]. Physical conditions are quite reverse for rice-maize system. Maize is grown in dry conditions whereas, rice is grown in wet land conditions. Rice grown in minimum tillage under unpuddled transplanting conditions decreased the production cost and increased the profitability (Islam *et. al.*, 2014) [9]. Unpuddled transplanting is gaining attention to the rice-growing farmers in India. Minimum tillage with residue retention under dry and wet conditions would change the chemical properties in rice-maize cropping systems. The present investigation was therefore undertaken to determine the effects of tillage and residue management on soil phosphorus fractions properties in different prevailing cropping systems.

## Materials and Methods

The experiment being carried out in agricultural research farm, Bihar Agricultural College, Sabour, Bhagalpur, Bihar which is geographically situated between 25°15' 40''N latitude and 7 8°02' 42''E longitudes situated at 45.57 meters above the sea level. The experiment was laid out in factorial randomized block design having three establishment methods in main plots, *i.e*. Zero tillage, permanent bed and conventional and three cropping systems in sub-plot, *i.e.* rice-wheat, maize-wheat and maize-maize.

For *kharif* season, Shbhagi and DHM117 varieties of crop were taken for rice and maize respectively. Whereas, in *rabi* season HD 2733 and P3396 varieties of crops were taken for wheat and *rabi* maize respectively. In *kharif* season, 80 N, 40 $P_2O_5$& 20 $K_2O$ kg were applied to rice crop and in maize 80 N, 40 $P_2O_5$& 20 $K_2O$ kg was given. Remaining agronomic package and practices were done as recommended for this area. Soil texture was sandy loam type with pH of 7.28.

The initial soil sample was collected randomly in duplicate from each plot with the help of a core sampler having a diameter of 5.0 cm and a height of 4.6 cm from two different depths (0-15 cm and 15-30 cm). The distribution of P in soil was determined using a modified version of Hedley *et al*. (1982) [8]. Procedure as outlined by Jalaliand Ranjbar, (2010) [10], which included, (a) soluble and exchangeable P. Two grams of soil from each sample were weighed and transferred to a 50 ml centrifuge tube, and different fractions were extracted by the sequential fractionation procedure *i.e.* soil extracted with 20mL of 2M KCl (labile P) by shaking for 2 h at room temperature with continuous agitation; residue from the first fraction extracted with 20mL of 0.1 M NaOH (Fe-Al-bound P) by shaking for 17 h with continuous agitation; residue from second fraction extracted with 0.5 M HCl (Ca-bound P) by shaking for 24 h with continuous agitation and lastly, the residue from the 3rd fraction is extracted with a 5:2 mixture of concentrated $HNO_3$ and $HClO_4$ (Res-P), followed by P determination from the digest. The amount of P in all extracts was determined using the colorimetric ascorbic acid method (Murphy and Riley, 1962) [19].

| Name of the fraction | Extractant used |
|---|---|
| Fe- and Al bound P | 0.1 M NaOH |
| Ca-bound P | 0.5 M HCl |
| residual P | 5:2 mixture of concentrated $HNO_3$ and $HClO_4$ |

The obtained field experiment data were analyzed by using two way standard analysis of variance (ANOVA) to determine the effects of various treatments. Critical difference (CD) at 5% level of probability and P values was used to examine differences among treatment means.

## Result and Discussion

### Iron and aluminium bound phosphorus fraction in soil

Tillage and cropping system showed significant impact on the Iron and Aluminium bound phosphorus content in surface (0-15 cm) soil. The highest Iron and Aluminium bound phosphorus was found in zero tillage system (ZT) followed by Permanent bed (PB) and conventional tillage (CT) system. The zero tillage system contained (6.64 mg P $kg^{-1}$) soil which was ~15% higher than conventional tillage system (5.75 mg P $kg^{-1}$). Whereas, Permanent bed system was contained (6.11 mg P $kg^{-1}$) Iron and Aluminium phosphorus that was ~6% higher than the conventional tillage system (Table 1). This finding is in conformation with the findings of Das *et. al.*, 2013 [4]. They reported that zero tillage system accumulates higher organic matter in the soil that accumulation also further augmented by the submergence and higher root biomass especially in rice-wheat cropping system. In cropping systems , Rice-Wheat (R-W) system had highest in Iron and Aluminium phosphorus content (7.44 mg P $kg^{-1}$) followed by Maize- Wheat system (6.25 mg P $kg^{-1}$) and Maize-Maize system (4.80 mg P $kg^{-1}$). The increment in Iron and Aluminium phosphorus content was ~16% and ~36% in Maize-Wheat (M-W) and Maize-Maize (M-M) cropping system respectively, over conventional Rice-Wheat cropping system (Table 1). The interaction of tillage and cropping system was also found to be significant. Zero till rice-wheat system (ZT-RW) was observed highest Iron and Aluminium phosphorus content (7.69 mg P $kg^{-1}$) among the all tillage and cropping system interaction and lowest was observed in Permanent bed tillage maize-maize system (4.26 mg P $kg^{-1}$) (Figure 1a). This fact may be due to that negatively charged functional groups in organic substances (e.g., carboxyl, phenol) can interact with positively charged minerals such as iron oxides and as a result, alter phosphorus adsorption.

Iron and Aluminium bound phosphorus in subsurface (15-30 cm) soil was significantly accredited with the tillage and cropping systems. The highest content was found in zero tillage system (ZT) followed by Permanent bed (PB) and conventional tillage (CT) system. The zero tillage system was contained 5.48 mg P $kg^{-1}$ soil which was ~22% higher than conventional tillage system (4.30 mg P $kg^{-1}$). Whereas, Permanent bed system was contained 4.85 mg P $kg^{-1}$ that was ~13% higher than the conventional tillage system (Table 1).

Similar trend was observed in cropping systems with surface phosphorus content. Rice-Wheat (R-W) system had highest Iron and Aluminium phosphorus content (5.84 mg P $kg^{-1}$) followed by Maize- Wheat system (4.92 mg P $kg^{-1}$) and Maize-Maize system (3.88 mg P $kg^{-1}$). The increment in Iron and Aluminium phosphorus content was ~16% and ~33% in Maize-Wheat (M-W) and Maize-Maize (M-M) cropping system respectively, over conventional Rice-Wheat cropping system. The interaction of tillage and cropping system was also found to be significant. Zero till rice-wheat system (ZT-RW) was observed highest Iron and Aluminium phosphorus content (5.01 mg P $kg^{-1}$) among the all tillage and cropping system interaction and lowest was observed in permanent bed tillage Maize-Wheat system (3.05 mg P $kg^{-1}$) (Figure 1a).

**Calcium bound phosphorus fraction in soil**

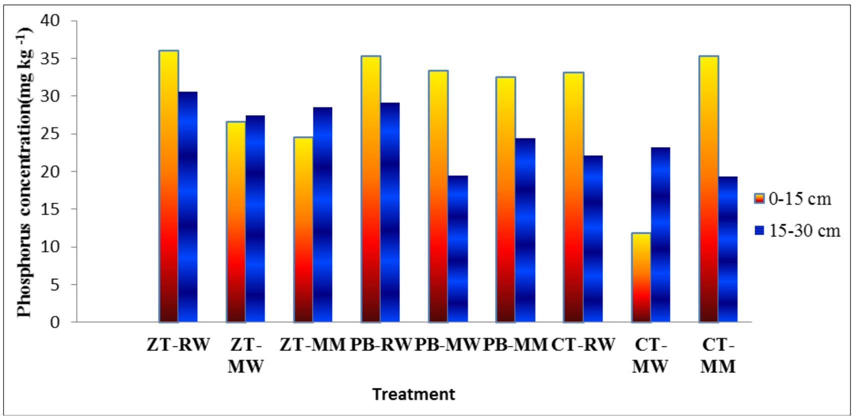
The Calcium bound phosphorus in soil (0-15 cm) was significantly varied with cropping systems but little affected by the tillage practices. The zero tillage system and Permanent bed system was contained (31.99 mg P kg-1) and (26.41 mg P $kg^{-1}$) soil respectively, which was ~21% and ~11% higher than conventional tillage system (Table 1). This could be attributed to the formation of insoluble Ca-P compounds in these soils having calcareous nature as $Ca^{2+}$ activity in the liquid phase is mainly responsible for formation of insoluble Ca-phosphate mineral in calcareous soil. In calcareous soils, the accumulation of $CaCO_3$ is believed to govern soil P reactions because of its adsorption and precipitation on the $CaCO_3$ surface (Lindsey 1979) [13]. Cropping systems show significant variation in Calcium bound phosphorus content. Rice-Wheat (R-W) system had highest Calcium bound phosphorus content (34.00 mg P $kg^{-1}$) followed by followed by Maize- Wheat system (30.54 mg P $kg^{-1}$) and Maize-Maize system (22.96 mg P $kg^{-1}$). The increment in Calcium bound phosphorus content was ~11% and ~33% in Maize-Wheat (MW) and Maize-Maize (M-M) cropping system respectively, over conventional Rice-Wheat cropping system (Table 1).The interaction of tillage and cropping system was also found to be significant at . Zero till rice-wheat system (ZT-RW) was observed highest Calcium bound phosphorus content (36.02 mg P kg-1) among the all tillage and cropping system interaction and lowest was observed in Conventional tillage Maize-Wheat system (11.81 mg P kg-1) (Figure 2a).

The Calcium bound phosphorus in soil below the plough layer (15-30 cm) was not significantly influenced by the tillage practices but cropping systems had shown marked influence in phosphorus content. The highest Calcium bound phosphorus was found in zero tillage system (ZT) followed by Permanent bed (PB) and conventional tillage (CT) system (Table 1). This may be due to the fact that apatite is the primary mineral of P which represents the calcium associated P in soils; P from this mineral is not readily available to plants (Williams *et al*. 1980) [25]. Organic acids such as oxalic and citric acids are released during the decomposition of soil organic matter and ecto-mycorhizal fungi, may increase calcium phosphate dissolution. In slightly weathered soils calcium associated inorganic P can be gradually convert into available P (Guo *et. al*. 2000) [6]. Cropping systems show significant variation in Calcium bound phosphorus content. Although Rice-Wheat (R-W) system had highest Calcium bound phosphorus content (29.68 mg P $kg^{-1}$) followed by Maize- Maize system (25.17 mg P $kg^{-1}$) and Maize-Wheat system (24.30 mg P $kg^{-1}$). The increment in Calcium bound phosphorus content was ~15% and ~18% in Maize-Maize (MM) and Maize-Wheat (M-W) cropping system respectively, over conventional Rice-Wheat cropping system (Table 1). Relatively lower proportion of calcium-aluminium associated inorganic P in soils may be attributed to the effect of organic matter returned to the Rice-wheat soil through litter fall and root biomass that has the ability to solubilize the native soil P (Gaume *et. al.*, 2001; Boschetti *et. al*., 2009) [1, 5]. Excretion of carboxilate, enzymes, and protons by roots and fungi participate in ligand exchange reactions with sesquioxides thereby increases the P molecules into soil solution. The interaction of tillage and cropping system was also found to be significant. Zero till rice-wheat system (ZT-RW) was observed highest Calcium bound phosphorus content (30.54 mg P $kg^{-1}$) among the all tillage and cropping system interaction and lowest was observed in Conventional tillage Maize-Maize system (19.31mg P $kg^{-1}$) (Figure 1b).

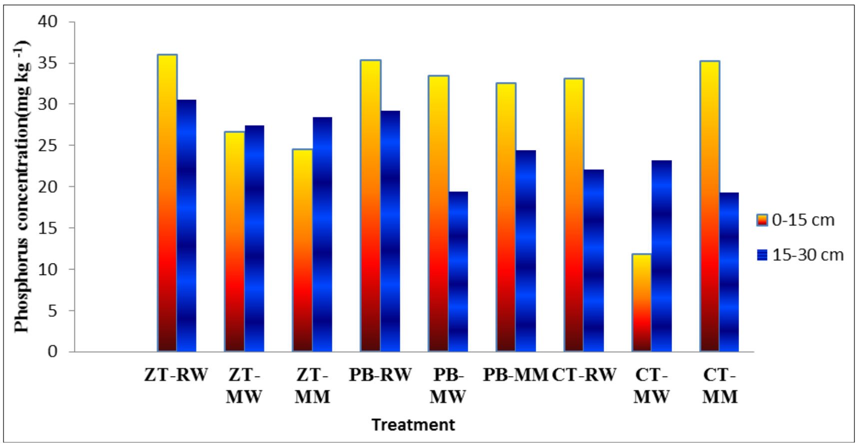
**Residual phosphorus fraction in soil**

The residual phosphorus in soil (0-15 cm) was significantly varied with the tillage and cropping systems. The highest residual phosphorus was found in zero tillage system (ZT) followed by Permanent bed (PB) and conventional tillage (CT) system (Table 1). The zero tillage system was contained (155.58 mg P $kg^{-1}$) soil which was ~30% higher than conventional tillage system (119.96 mg P $kg^{-1}$). Whereas, Permanent bed system was contained (131.66 mg P $kg^{-1}$) residual phosphorus that was ~10% higher than the conventional tillage system with albeit significance (Table 1). These results emphasized the idea that there is Po accumulation in NT, especially in surface layers (Tiecher *et. al*., 2012) [22]. Cropping systems show significant variation in residual phosphorus content. Although Rice-Wheat (R-W) system had highest residual phosphorus content (157.86 mg P $kg^{-1}$) followed by Maize-Wheat system (139.73 mg P $kg^{-1}$) and Maize-Maize system (109.55 mg P $kg^{-1}$).

Tillage practices did not showed any significant impact on residual phosphorus content at 15-30 cm soil depth. Zero tillage (117.34 mg P $kg^{-1}$) and Permanent bed (114.53 mg P $kg^{-1}$) attributed 2-4% higher phosphorus content as compared to conventional tillage (112.49 mg P $kg^{-1}$) practices (Table 1). Cropping systems show significant variation in residual phosphorus content. Rice-Wheat (R-W) system had highest residual phosphorus content (150.90 mg P $kg^{-1}$) followed by Maize-Maize system (111.89 mg P $kg^{-1}$) and Maize- Wheat system (91.57 mg P $kg^{-1}$). There was no effect of treatments on residual P, although this fraction does not participate in the availability of P for plants (Stewart and Sharpley, 1987) [21] but serve as a reserve of available P in long run.




(a)




(b)

**Fig 1:** Influenced of tillage practices and cropping systems on (a) Iron and Aluminium Bound Phosphorus content (b) Calcium Bound Phosphorus content at 0-15 cm and 15-30 cm soil depth. (ZT- Zero Tillage, PB- Permanent Bed, CT- Conventional Tillage, RW- Rice-Wheat, MW- Maize-Wheat, MM- Maize-Maize)

**Table 1:** Effect of tillage practices and cropping system on Phosphorus fraction in soil under irrigated agro- ecosystems.

| Treatment | Fe and Al bound Phosphorus (0-15 cm) | Fe and Al bound Phosphorus (15-30 cm) | Ca bound Phosphorus (0-15 cm) | Ca bound Phosphorus (15-30 cm) | Residual Phosphorus (0-30 cm) | Residual Phosphorus (15-30 cm) |
|---|---|---|---|---|---|---|
| mg P kg$^{-1}$ | | | | | | |
| **Tillage Practice** | | | | | | |
| Zero Tillage (ZT) | 6.64 | 5.48 | 31.99 | 28.91 | 155.58 | 114.53 |
| Permanent Bed (PB) | 6.11 | 4.85 | 29.10 | 27.28 | 131.66 | 117.34 |
| Conventional Tillage (CT) | 5.75 | 4.30 | 26.41 | 22.96 | 119.96 | 112.49 |
| **Cropping system** | | | | | | |
| Rice- Wheat (R-W) | 7.44 | 5.84 | 34.00 | 29.68 | 157.86 | 150.90 |
| Maize- Wheat (M-W) | 6.25 | 4.92 | 30.54 | 24.30 | 139.73 | 91.57 |
| Maize- Maize(M-M) | 4.80 | 3.88 | 22.96 | 25.17 | 109.55 | 111.89 |
| SEm | 0.07 | 0.12 | 1.74 | 0.66 | 7.87 | 3.20 |
| CD(p<0.5) | 0.21 | 0.36 | 5.18 | 1.96 | 23.37 | 9.51 |
| CV (%) | 3.48 | 7.31 | 7.76 | 7.42 | 7.23 | 8.06 |

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