Effect of fertilization on soil phosphorus and its fraction in soil

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Abstract: Phosphorus fractions are important for evaluation of their status in soil and understanding of soil chemistry that influence soil fertility. Amount and distribution of P in different fractions of soil. Soil P fractionation gives an idea about the soil P supplying capacity to plants. The dissolved phosphate ion is the only form that plants can take up, yet in the surface layer of most agricultural soils there is less than 1 mg/L (1 ppm) of dissolved phosphate in the soil solution (soil water), except in recently fertilized soils. On the other hand, the total soil P concentration can vary from about 200 to 2,000 ppm depending greatly on soil parent material. The present experiment was conducted to evaluate the effect of different nutrient management. Investigations from researchers have shown the efficacy of the ion-sink methods especially the resin membranes which extract soil-available P in a similar manner as plant roots does. It can be employed for a variety of soil types irrespective of their properties.

Key word: Phosphorus availability, Different forms, Fertilization, Management

Introduction
Phosphorus is the tenth most abundant element in the earth’s crust. Its average content in the earth crust is nearly 0.12 per cent. In lithosphere, it always occurs in the pentavalent oxidation state. Nearly 200 phosphate minerals have been reported to occur in nature. The most important of all these minerals is the apatite group, of which fluorapatites constitute the bulk of the commercial source of phosphates. Therefore, maintenance of an adequate amount of soil P through application of inorganic and/or organic P is critical for the sustainability of cropping systems (Sharpley et al., 1994). Phosphorus in soil is present in both organic and inorganic forms. In general, inorganic P is the predominant form of soil P, constituting 20 to 80% of the total P in the surface layer (Tomar 2003). It is the inorganic fraction, which is more intimately related to phosphate nutrition to plants in agricultural soils. Plant availability of inorganic P can be limited by the formation of sparingly soluble calcium phosphate in alkaline and calcareous soils; by adsorption onto Fe and Al oxides in acid soils and by formation of Fe and Al phosphate complexes with humic acids (Gerke 1992). The nature and distribution of different forms of P have provided useful information for assessing the available P status of soil and for estimating the degree of chemical weathering of the soil, P deficiency, etc. Estimation of available P indicates only the amount of P present in soil solution and soil surface which is available to plants but it does not indicate about the relative contribution of different fractions of P towards available P. Thus understanding of the relationship between various forms of P; their interactions in soil and various factor influencing P availability to plants is essential for efficient P management in soil.

The availability and fractions of soil P may change due to long-term continuous P fertilization besides its yield-increasing effect (Fan et al., 2003; Lai et al., 2003). The knowledge of soil P fractions is important for investigating soil P availability, and several kinds of fractionation methods are available for different soil types (Chang and Jackson, 1957; Hedley et al., 1982; Jiang and Gu, 1989). Chemical fractionations of soil inorganic phosphorus small amounts of iron or aluminum oxides. For example, provides a method for identifying the predominate Ryan et al. showed that P sorption in 20 Lebanese individual forms of inorganic P in soils, most commonly calcareous soils was related to oxalate-extractable Fe, i.e. soluble P, Al-P, Fe-P, occluded P and Ca-P . amorphous forms of iron oxides. Fractionation of inorganic P is commonly carried out Samadi and Gilkes 1998 demonstrated that Al-P and Fe to characterize the effects of soil types and P sources P were amongst the most important forms of P in virgin on the fate and potential availability and mobility of and fertilized calcareous soils from Western Australia. Therefore, the paper deals with the effect of fertilization on soil phosphorus and its fractionation in soil. The available literature related to the present study has been reviewed under the following heads.

Plant-availableability in soil: Phosphorus exists in the soil as dissolved orthophosphate in solution (mainly HPO_4^{2-} or H_2PO_4^- depending on soil pH), sorbed P on the surface of organic or inorganic compounds, or as part of organic P compounds or P minerals. The dissolved phosphate ion is the only form that plants can take up, yet in the surface layer of most agricultural soils there is less than 1 mg/L (1 ppm) of dissolved phosphate in the soil solution (soil water), except in recently
fertilized soils. On the other hand, the total soil P concentration can vary from about 200 to 2,000 ppm depending greatly on soil parent material and histories of cropping and fertilizer or manure application. Organic P normally represents about 25 to 65% of total P in surface soils, depending mainly on soil organic matter content. Organic P usually decreases abruptly with soil depth, paralleling decreases in organic matter. The processes that control the amount of plant available P in the soil are plant uptake, sorption/desorption, mineralization/immobilization, precipitation/dissolution, runoff, and leaching. Because of the usually very small concentration of P in the soil solution, an understanding of these processes is important for implementing good P management.

Available-P is often used to express the amount of soil P in solution which can be extracted or mined by plant roots and utilized by the plant for growth and development during its life cycle. It is also referred to as labile P. The concentration of available-P is always low because of continuous plant uptake. This is further complicated by the slow replenishment of the extracted P from the soil solution by the labile pool which is dictated by the soil P equilibria (Holford, 1997). This is however, favoured by an application of P-amendment source like fertilizers or manure. The concentration of available-P pool is dictated by the prevailing soil conditions at a particular time and the ability of the crop to extract the P from the soil solution. Therefore, it is a quantity or extensive parameter (Raven and Hossner, 1993; Holford, 1997). Phosphorus is released at a faster rate from the labile pool into the soil solution at lower buffering capacity. Holford (1997) reported 3 important soil components controlling the supply of P from the labile pool to replenish crop extraction. These include the amount of or concentration of P in the soil solution; the amount of P in the replenishment source that enters into equilibrium with the soil solution phase and P buffering capacity of the soil.

Phosphorus retention in soils: Inorganic P dynamics in soils are dominated by processes of sorption/desorption and precipitation/dissolution. Sorption refers to the binding of P to the surface of soil particles. Phosphorus sorption/desorption reactions are strongly influenced by soil pH, texture, and mineralogy of fine soil particles. For example, orthophosphate reacts strongly with aluminum (Al) and iron (Fe) oxides and hydroxides, especially at low pH, and also with carbonates in high-pH soils. Fine textured soils generally can sorb more P because they have higher clay concentration and greater surface area. Dissolved organic compounds from recent organic matter additions can increase P availability by blocking sites or coating Fe/Al oxides. Phosphorus desorption generally increases as solution P decreases due to plant uptake or leaching, and also under flooded or waterlogged conditions due to changes of Fe hydroxides and oxides to more soluble forms. When high P fertilizer rates are applied, P sorption sites can become partially saturated, which increases the recovery of added P but can also increase dissolved P loss through the soil profile or surface runoff.

Phosphorus fraction: Phosphorus in soil occurs as saloid bound phosphorus, Al-bound phosphorus, Fe-bound phosphorus, reducible soluble phosphorus, Ca-P and organic P. Since, these forms of phosphorus have different solubilities, the availability and uptake depend upon their amount in the soil. The forms of phosphorus are influenced by soil characteristics such as texture, soil reaction, calcium carbonate and organic matter content. Combined use of fertilizers with manures influences the form and availability of soil Phosphorus and Potassium in many ways. The proportion of forms of phosphorus such as Ca-P, Al-P, Fe-P, reducible soluble-P, organic P governs the response to applied P (Singh et al., 2003). Therefore, the present study was carried out to determine the forms of phosphorus. The conversion of applied P into specific inorganic forms is important, as the fertilizer reaction product is the source of phosphorus from soil.

The knowledge of soil P fractions is important for investigating soil P availability, and several kinds of fractionation methods are available for different soil types (Chang and Jackson, 1957; Hedley et al., 1982; Jiang and Gu, 1989). In calcarous soils, soil inorganic P (Pi) represents the dominant component of the soil P pool, accounting for about 75%–85% of soil total P in calcarous soils in China (Jiang and Gu, 1989). Soil Pi was divided into various fractions such as Ca-P (HCl extractable P), Fe- and Al-P (non-occluded Fe- and Al-bound P), and occluded P (Chang and Jackson, 1957; Solis and Torrent, 1989). However, in calcarous soils, the majority of Pi exists in the various Ca-bound forms and there is a great difference in P availability among the Ca-P fractions. To better characterize Pi transformations, Jiang and Gu (1989) proposed a fractionation scheme for calcarous soils based on the methods described by Chang and Jackson (1957) and Hedley et al. (1982), where soil Pi was divided into six fractions (Ca2-P, Ca8-P, Al-P, Fe-P, occluded P, and Ca10-P) using a sequential extraction procedure, based on their availability and solubility. This has been confirmed by Gu and Qin (1997), Samadi and Gilkes (1998), Lai et al. (2003), and Shen et al. (2004) based on the simple correlation coefficients between Olsen-P and Pi fractions. The contents of all Pi fractions but Ca10-P increased after fertilizer P applications as shown in Table I, although no significant differences were found among two low fertilizer P levels and no fertilizer P treatment for Ca8-P, Al-P, Fe-P and occluded P. Table II also showed a high correlations coefficient between fertilizer P rates and all Pi fractions but Ca10-P. The slope of linear correlation equations between Olsen-P and Pi fractions. The contents of Pi fractions after fertilizer P application had a more positive impact on the accumulation of soil Ca8-P than the other fractions, which is consistent to the results from Samadi and Gilkes (1998). The contents of Pi fractions after fertilizer P application were in the order of Ca10-P > Ca8-P > Fe-P > Al-P > occluded P > Ca2-P, and only Al-P exceeded occluded P when comparing to that without fertilizer P application (Fig. 1).

Table-1: Details of P-fractionations scheme used

<table>
<thead>
<tr>
<th>Extraction</th>
<th>pH</th>
<th>P-Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 M NaHCO3</td>
<td>7.5</td>
<td>Di-calcium phosphate (Ca2-P)</td>
</tr>
<tr>
<td>NH4-AC 0.5 M</td>
<td>4.2</td>
<td>Octa-calcium phosphate (Ca8-P)</td>
</tr>
<tr>
<td>0.5 M NH4F</td>
<td>8.2</td>
<td>P-adsorbed by Al oxides (Al-P)</td>
</tr>
<tr>
<td>0.1 N NaOH-0.1 N Na2CO3</td>
<td></td>
<td>P-adsorbed by Fe oxides (Fe-P)</td>
</tr>
<tr>
<td>0.3 M Na2Cit-Na5S2O3-NaOH</td>
<td></td>
<td>Occluded-P (O-P)</td>
</tr>
<tr>
<td>0.5 N H2SO4</td>
<td></td>
<td>Apatite (Ca10-P)</td>
</tr>
</tbody>
</table>

(Source: Mostashari et al., 2008)
The plants mainly depend upon inorganic forms for their phosphorus requirements. It has now been established that saloid-P, Al-P, Fe-P, Reductant-P and Ca-P are the major soil inorganic P fractions and their relative proportion depended upon various factors. Jaggi (1991). Pavan and Androcioli (1995) studied the effects of NP + Green manure + compost and NPK + green manure + compost + grass straw mulch on P fractions in a latosol using a sequential extraction procedure. Moderately labile P (NaOH-Po, NaOH-Pi) and non labile P (HCl-Pi, residual P) were significantly increased by the application of compost and mulch. NaHCO3-Pi and resin-P accounted for the largest proportion of inorganic and organic P, respectively. The residual P fraction was the smallest fraction of total P; it was not affected by any of the treatments and increased with soil depth. Exclusive application of inorganic fertilizers increased both non-labile and poorly labile fractions. Bahl and Singh (1997) conducted laboratory and green house experiments in ten soils (eight alkaline and two acid soils) to study the effect of added P, green manuring and cropping on Olsen’s P and inorganic soil P fractions. P-fertilization resulted in increase in all the estimated P-fractions. Due to green manure addition, Saloid-P increased at the expense of other P fractions. Vasuki et al. (1998) analyzed surface sample (0-20cm) of Alfisols collected from 5 tobacco-growing areas of Karnataka, India and revealed that the Saloid-P fraction was the smallest (2.1-8.9 ppm), while Al-P and Fe-P were the dominant fractions. The concentration and contribution of each fraction to total P was in the order: Saloid-P < occluded-P < Ca-P < reductant-P < Al-P < Fe-P. Among the properties, pH, organic carbon and free iron oxides were found to have the greatest influence on the inorganic P fractions. Two field experiments were conducted in Poland to determine the effects of applied farmyard manure (FYM), cattle slurry (CS), pig slurry (PS) and mineral fertilizer (MF) on the content of total, organic and mineral P in soil lessive and brown soil. The influence of fertilizer application on the uptake and utilization of P by cultivated plants was also determined. Long term fertilizer application contributed to a significant increase in the content of total, organic and mineral P in the soil. P utilization from fertilizers applied to soil lessive was higher than from those applied to brown soil. (Sadej, 2000). Lee et al. (2004) found that continuous fertilizer application and rice cultivation led to a continuous decrease in ratio of organic P to total P in the plough layer with the lapse of years. In conclusion, the combined application of chemical fertilizers and compost could be an effective method to increase the plant availability of P in soils by promoting microbial activity. Sheeba and Kumaraswamy (2005) revealed that amongst manures, urban compost applied at 12.5 t/ha improved the maximum status of total P (895 ppm) and organic (143 ppm) and inorganic P (743 ppm) followed by FYM at 12.5 t per ha. However, available P was the highest (78 kg/ha) in the plots receiving FYM followed by urban compost (72 kg/ha). Amongst fertilizers, the maximum values of total P (874 ppm), inorganic P (709 ppm) and available P (85 kg/ha) were found in NPK at 120:60:60 with almost at par value in the fertilizer treatments receiving 60 kg P per ha, organic P content was also almost similar in all the P receiving fertilizer treatments.

A study was undertaken to evaluate the effect of chemical fertilizers and organic manures on the amount and distribution of P fractions in soil after two cycles of rice-wheat cropping system. There was a significant increase in saloid-P; Al-P and Ca-P as result of inorganic fertilization and organic amendments which could be attributed to the transformation of applied P at faster rate into saloid-P, Al-P and Ca-P in the first instance and then to Fe-P with time (Sihag et al., 2005). Guppy et al. (2005) reported that the incorporation of organic matter in soils that are able to rapidly absorb applied phosphorus fertilizers reportedly increased phosphorus availability to plants. Joshi (2006) reported that under long-term fertilizer management in Vertisol, maximum portion of applied P was transformed in Ca-P followed by Red-P, Fe-P and Al-P. In case of potassium, maximum portion of applied K was transformed into non-exchangeable K and minimum into water soluble K, whereas exchangeable K and available K were intermediate. Bhakare et al. (2006) revealed that there was highly significant positive relationship between yield and all the fraction of P in Inceptisol of Maharashtra. The significant positive correlation was also observed between all the forms of P, P uptake and available P. Total P had highest relationship with P uptake and available P (0.939** and 0.971 respectively). Dutta et al. (2007) studied the physico-chemical properties of the soils and showed that the soils were acidic (pH: 4.21 to 5.67) in nature with moderate to high in organic carbon content. Avid variation was observed in extractable P, extractable Al, amorphous Al and exchangeable cations. The different inorganic forms of soil P, were in decreased in the order of Al-P > Fe-P > reductant soluble P > Ca-P > occluded P > saloid P. Majumdar et al. (2007) reported that among inorganic fractions, significantly increase in saloid-P, Al-P, Fe-P and Ca-P but depletion in reductant-soluble and occluded-P was observed. The P use efficiency was higher at lower doses of applied P with the maximum value (21.3%) recorded with SSP @ 30 kg P.O. ha-1+FYM treatment. Application of 60 kg P2O5 ha-1 through SSP alone or with FYM was most efficient dose for production of high quality soybean and forms of P build up followed by 60 kg P.O2 ha-1 as SSP + RP (1:1) with or without FYM in acidic Alfisol of Meghalaya. Jatav et al. (2010) revealed significant variation in different fractions of phosphorus and potassium and soil chemical properties in a field experiments conducted during 2004-05 to 2006-07 at central potato research institute’s farm on brown soils in mid hills of Shimla. Fractionation studies revealed significant increase in saloid-P, Al-P, Ca-P and various forms of K under integrated use of inorganic fertilizers and FYM.
Table-2: Concentrations of soil Pi fractions after long-term fertilizer P applications at the Changwu Agro-ecological Experimental Station

<table>
<thead>
<tr>
<th>Fertilizer rate (kg P ha(^{-1}))</th>
<th>Ca2-P (mg kg(^{-1}))</th>
<th>Ca8-P (mg kg(^{-1}))</th>
<th>Al-P (mg kg(^{-1}))</th>
<th>Fe-P (mg kg(^{-1}))</th>
<th>Occluded-P (mg kg(^{-1}))</th>
<th>Ca10-P (mg kg(^{-1}))</th>
<th>Total Pi (mg kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.5da</td>
<td>70.3b</td>
<td>10.2c</td>
<td>26.6c</td>
<td>13.1b</td>
<td>296.7a</td>
<td>296.7a</td>
</tr>
<tr>
<td>20</td>
<td>10.2c</td>
<td>88.2b</td>
<td>16.6bc</td>
<td>34.2c</td>
<td>13.4ab</td>
<td>342.0a</td>
<td>504.6b</td>
</tr>
<tr>
<td>39</td>
<td>10.7bc</td>
<td>114.8b</td>
<td>21.8bc</td>
<td>37.8bc</td>
<td>17.2ab</td>
<td>288.4a</td>
<td>490.7b</td>
</tr>
<tr>
<td>59</td>
<td>14.5ab</td>
<td>200.0a</td>
<td>44.4ab</td>
<td>49.0ab</td>
<td>20.4ab</td>
<td>365.5a</td>
<td>693.8a</td>
</tr>
<tr>
<td>79</td>
<td>16.3a</td>
<td>242.2a</td>
<td>56.0a</td>
<td>57.4a</td>
<td>24.0a</td>
<td>341.8a</td>
<td>737.6a</td>
</tr>
</tbody>
</table>

Regression equation with fertilizer P rate (n = 15)

- **Slope**: 0.14
- **Intercept**: 5.67
- **r^2**: 0.79
- **P**: <0.001

(a) Values within one column followed by the same letter(s) are not significantly different at P <0.05; (b) Not significant (Source: Wang Jun et al., 2010)

Depth-wise distribution of different form of soil phosphorus:
Saque et al. (2004) reported that long-term effects of rice (Oryza sativa L.) cultivation with varying nutrient management on soil P fraction are important to understand from soil nutrition. The P fractionation study was conducted over the treatments and soil depth. The depletion of NaHCO\(_3\)-P and NaOH-Pi at the 0 to 15 cm depth under control and T\(_1\) (one-third of recommended fertilizer doses) suggests that the rice plant depends upon these fractions of P. The P depletion profile in wetland rice appears to be confined within the first 15 cm depth. The mean P uptake by rice showed a polynomial relationship with NaHCO\(_3\)-P and NaOH-Pi (average of 0–15 cm) and it was linearly correlated with acid P (0–15 cm). Maximum build up in soil P fractions were observed with the application of 150 per cent chemical fertilizer followed by 100 per cent fertilizer application alone or with FYM. It was noted that the integration of chemical fertilizer with BGA and green manure resulted in a higher build up of all soil P fractions. The buildup of P fraction can be attributed to its lower uptake both by rice and wheat crops than its application that resulted in its accumulation as phosphorus is an immobile element and therefore is not likely to be lost by leaching. This trend of P build up as a result of long term INM practice has also been reported by Rokima and Prasad, (1991) and Sihag et al. (2005). Majumdar et al. (2007) reported that among inorganic fractions, significantly increase in saloid-P, Al-P, Fe-P and Ca-P but depletion in reducant-P soluble and occluded-P was observed. The P use efficiency was higher at lower doses of applied P with the maximum value (21.3%) recorded with SSP at 30 kg P\(_{2}O\(_5\) ha\(^{-1}\) + FYM treatment. Application of 60 kg P\(_{2}O\(_5\) ha\(^{-1}\) through SSP alone or with FYM was most efficient dose for production of high quality soybean and forms of P build up followed by 60 kg P\(_{2}O\(_5\) ha\(^{-1}\) as SSP + RP (1:1) with or without FYM in acid Alfisol of Meghalaya.

Barancikova et al. (2007) reported that soil phosphorus (P) can exist in various inorganic (Pi) and organic forms (Po). Specific determination of Pi can be obtained by fractionation methods. In this paper, the determination of various phosphorus forms (available P, total P, Pi and Po fractions) in arable and mountain soils is presented. Besides, the detailed characterization of P compounds in humic acids (HA) is also shown. The results obtained show that the highest content of the available P can be found in arable soils with a high input of fertilizers, and that the predominant part of Pi is included in hardly soluble fractions, mainly in the soil types with neutral soil reaction. Our data also show the correlation between total P and Po, the dominant form of P in the topsoil of mountain soils. Thakur et al. (2010) The results of the continuous use of N alone or NP had deleterious effect on long term fertility and sustainability. The availability N and P content decreased in the soil depth, whereas available K decreased up to half meter and then gradually increased. Trivedi et al. (2010) revealed that the Olsen-P, Al-P, Fe-P, Red-P and Total-P decreased with increase in the depth of soil. Similar findings were also reported by Tiwari et al. (2012). In acid soils of Meghalaya, Laxminarayana, (2011) 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. Tiwari et al. (2012) studied different fractions of P under three cropping systems. In rice based cropping system values of Fe-P was the lowest, while Al-P was low in okra based cropping and Ca-P is low in pea based cropping cropping pattern. Available P was relatively higher in potato based cropping patterns.

Lungmuana et al. (2012) observed the dominance of reducant soluble phosphate and iron phosphate and less amount of saloid bound phosphate and calcium phosphate in red and laterite zone of West Bengal were observed. Sharma and Tripathi (1982) studied phosphorus fractions of surface layer of some acid hill soils of north-west India and revealed that these soils were fairly rich in total P reserve (average 493 ppm). The average contribution of four fraction (S-P; Al-P, Fe-P, Ca-P and Reductant-P) was 0.8, 5.9, 15.6, 5.8 and 21.5 per cent, respectively. Patgiri and Datta (1993) studied the forms and distribution of phosphorus in some tea growing acid soils and reported that the total P content varied from 810 to 1162 ppm. The contribution of different fractions towards inorganic P was as follows. Al-P (49.5%) > Fe-P (35.9%) > RS-P (7.9%) > Ca-P (6.6%).

Management practices for P fertilization: Sample soil as frequently and as densely within fields as economically possible and use appropriately calibrated soil-test methods based on research for each state or region. Consider yield levels and crop P removal across and within fields to help maintain optimum soil test P levels in conjunction with soil testing. Fertilize P deficient soils using environmentally and economically sound agronomic guidelines. In general, soils testing ‘high’ or “very high” will not respond economically to additional P and should not receive fertilizer except for starter in certain known and specific conditions. Divide large, non-uniform fields into smaller fertility management units based upon yield potential, soil tests, and relevant soil properties. Credit all available P from manures and other organic sources when deciding the P application requirements for crop. Refer to local research and guidelines concerning P placement methods to optimize P use efficiency, the profitability of nutrient application, and water quality protection. Incorporate or inject high rates of inorganic or organic P sources into the soil where the risk of surface runoff or soil erosion is high. Use manure nutrient analysis and P risk assessment tool such as the P Index in order
to utilize as much manure nutrients as much as possible without increasing the risk of P loss and water quality impairment.

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Reference

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