Release behavior of phosphorus and its fractions in different phosphorus status soils

Abstract

Phosphorus is essential to all forms of life and its contribution towards aiding the native soil fertility and sustaining it, is well known. With passage of time, P added to soil undergoes transformation into various unavailableforms. Native P compounds, some being highly insoluble are mostly are unavailable for plant uptake. The availability of phosphorus to the plants depends on soil properties, soil pH, soluble iron, aluminum and manganese, calcium minerals, organic matter, activities of microorganisms thus availability of Pmay varyaccording to soil types. Knowing the changes in P fractions inespecially in low and inhighP status soils is much more important for P availability to plant. Therefore, the release behavior of phosphorus and its fraction in different P status soils was assessed over 5 weeks under laboratory incubation periods using a sequential fractionation procedure. The results of the experiment revealed that the content of available P and different P fractions were higher in high P status soil as compared to low P status soil.Among the various P fractions, Ca-P was the dominant fraction in both soils. The release of available P was first increased up to 21 and 28 days in low and high Pstatus soil, respectively and therelease of different forms of P fractions in both soils increased up to 28 days after incubation and then decreased with further increase in incubation period.

Keywords: Phosphorus, fraction, incubation, status, release behavior

Introduction

Phosphorus is one of the most important nutrient element after nitrogen in crop production as it is vital for several functions such as photosynthesis, protein information, nucleic acid production, transformation of sugar to starch, nitrogen fixation and oil formation (Mehrvarz and Chaichi, 2008).It's availability to plants is a major issue as soil phosphorus is least mobile contrary to the other macronutrients and hence less available nutrient. Its low availability in soil is due to fixation of P asoxides or hydroxides to Fe and Al or other amorphous minerals (Gichangi*et al*., 2009) and its releasebehavior in soil has been ascribed to different adsorption, desorption reactions and precipitation or dissolution processes (Barrow, 1980;Lair *et al*., 2008). Phosphorus in soil is present in inorganic and organic forms and its different forms exist in different amounts and proportions, depending on soil type and management (Sharpley 2000). Phosphorus fractionation provides an effective approach for investigating soil P availability and P transformation in soil (Song *et al*.2007). The phosphorus adsorption capacity depends upon number of factors like pH, clay content and organic matter (Pheav et al., 2002). Devau*et al*., 2010 stated that clay content has major effect on P retention in soil. In addition to these properties, adsorption also depends on temperature and contact time between soil and P (Indinti*et al*., 1999). After the initial adsorption, P can become less labile with time, perhaps by diffusive penetration of adsorbed phosphate ions into the internal structure of components (Pierzynski, 1991; Lair *et al.*, 2009).Adsorption from added P was found at initially low levels but, slowly increased with increasing incubation period. This might be due to desorption of greater number of P ions (Agbenin and Tissen, 1995, Rajput *et al*., 2014). The P absorbed by plants directly comes from the soil solution, and there is a dynamic equilibrium between P in the soil solution and on the surface of clay particles (Barrow 1983). Such equilibrium is governed by P sorption and release from the solid phase and plant P uptake (Sharma *et al*., 1995). Hence the release rate of absorbed phosphorus directly affects the P supply to plants (Hughes *et al*., 2000). Therefore, the objective of thisstudy was to study the release behavior of two different phosphorus status soils for available P and different P fractions at different periods of incubation.

2. Materials and methods

2.1. Soils

The soils of different P status ([on the basis of 0.5M sodium bicarbonate (NaHCO3) extractable-P]) used in the present investigation were collectedfrom the farmer's fields from two different locations of Haryana *viz.*Sadalpur (Hisar) and Saniyana (Fatehabad). Soil collected from village Saniyana was high in available P whereas, collected from villageSadalpurwas low in available P content. The application of phosphorus fertilizer is being practiced by the farmers in both soils. These soil samples were brought to the laboratory. The soil samples of two soils were air dried, crushed and sieved (2mm) and analyzed for various physico-chemical properties (*i.e.* texture, pH, electrical conductivity, organic carbon, cation exchange capacity and available (N, P and K) by using standard methodology.

2.2. Phosphorus release behavior study

To study the release behaviorof available P and its fractions in differentP status soils, 100 g processed soils were taken into wide mouth plastic bottles (in triplicates) from low and high P status soils. After maintaining the moisture content at field capacity these bottles were placed in an incubator. Both the soils were incubated at room temperature (25^0C± 2 °C) for 1, 7, 14, 21, 28 and 35 days.A subsample of soil from each bottles and at each date was taken out and subjected for the analysis ofavailableP and different P fractions (saloid-P, aluminium-P, iron-P, reductant soluble-P, calcium-P and organic-P). A sequential fractionation for soil inorganic phosphorus was performed by following a method outlined by Chang and Jackson, 1957 and modified by Peterson and Corey, 1966. Different fractions of soil P were extracted by using different extractants.

3. Results

The physico-chemical properties presented in Table.1 revealed that both the soils were non-saline and neutral in reaction.The texture of the low available P status soil was sand (92% sand, 4% silt and 4% clay) and the soil s'pH was 7.4, electrical conductivity (EC): 0.12 dS m^{-1}, organic carbon (OC): 0.15% and cation exchange capacity (CEC): 4.46 cmol (p+) Kg^{-1}. The available N, P and K content of the soil was 28, 8 and 112 kg ha^{-1}, respectively. The DTPA-extractable Zn, Fe, Cu and Mn were found 0.3, 2.11, 1.94 and 2.48 mg kg^{-1}, respectively. In contrast, the soil with high available P status had a sandy loam texture (60% sand, 24% silt and 16% clay) and the pH of the soil was 7.1, EC: 1.0 dS m-1, OC: 0.62% and CEC: 9.28 cmol (p+) Kg^{-1}. The available N, P and K content of the soil was 182, 25 and 430 kg ha^{-1}, respectively. The DTPA-extractable Zn, Fe, Cu and Mn were found to be 0.72, 18.74, 3.08 and 10.26 mg kg^{-1}, respectively. In general, high P status soil had higher CEC than low P status soil. The OC content of high P status soil was found to be in medium range while that of low P status soil was found to be low. When compared to high P status soil, low P status soil had a lower levels of available N, P, K, and DTPA-extractable micronutrients (Zn, Cu, Fe, and Mn)and all macro (N, P and K) and micronutrients (Zn, Fe, Cu and Mn) were found to be present in higher concentration in high P status soil than in low P status soil.

Table 1: Initial physico-chemical properties of low and high phosphorus status soils

Initial soil parameters	Low P status Soil	High P status Soil
pH	7.4	7.1
EC (dS m^{-1})	0.12	1.0
Sand (%)	92	60
Silt (%)	4	24
Clay (%)	4	16
Texture	Sand	Sandy loam
CEC [(cmol (p^+) kg^{-1})]	4.46	9.28
Organic carbon (%)	0.15	0.62
Available Nitrogen (kg ha^{-1})	28	182
Available Phosphorus (kg ha^{-1})	8	25
Available Potassium (kg ha^{-1})	112	430
DTPA-extractable Zinc (mg kg^{-1})	0.30	0.72
DTPA-extractable Copper (mg kg^{-1})	1.94	3.08
DTPA-extractable Iron (mg kg^{-1})	2.11	18.74
DTPA-extractable Manganese (mg kg^{-1})	2.48	10.26

3.1. Release behavior of available P

During the course of the incubation period, changes in the release behavior available P (fig.1) revealed that the content and the release behavior of available P in both the two soils varied.Available P was found to be larger in magnitude in high P status soil as compared to the soil with low P status and also appeared to peak at 21 DAI in low P status soil and 28 DAI in high P status soil. In low P status soil, available P content increased from 7.91 to 17.4 kg ha^{-1} with increase in incubation period from 1 to 21 days, thereafter, it decreased to 9.10 kg ha^{-1} at 35 days of incubation. In contrast, in high P status soil, the increase in available P content was observed up to 28 days after incubation (DAI) and after which it was decreased. The content of available P in high P status soil increased from 24.87 to 98.01 kg ha^{-1} with increase in incubation period from 1 to 28 days, thereafter, it decreased to 87.93 kg ha^{-1} at 35 days of incubation.According to Shariatmadari*et al.* (2005) the gradual decrement of P release in the two soils with time might be due to the decreased surface charge and interaction between the adsorbed P ions. However, in low and high P soils, at 1^{st} DAI, the content of availableP decreased from their initial values 8.00 and 25.00 kg ha^{-1}, respectively.The content of available P was comparatively higher in high P status soil than low P status soil.This may be due to the higher initial P content and higher OC content of high P status soil. The results of the study are in agreement with the findings of Rajput *et al.* (2014) and Kaloi*et al.* (2011). They reported that high organic matter content resulted in lesser P adsorption whereas high clay in combination with calcium carbonate contents increased the adsorption of phosphorus. Similar results regarding P release behavior increased through incubation period was also reported by Dey *et al.* (2019) and McDowell and Sharpley, (2003). Moharana*et al.* (2015) also indicated that materials with high P content and high OC content release more phosphorus.

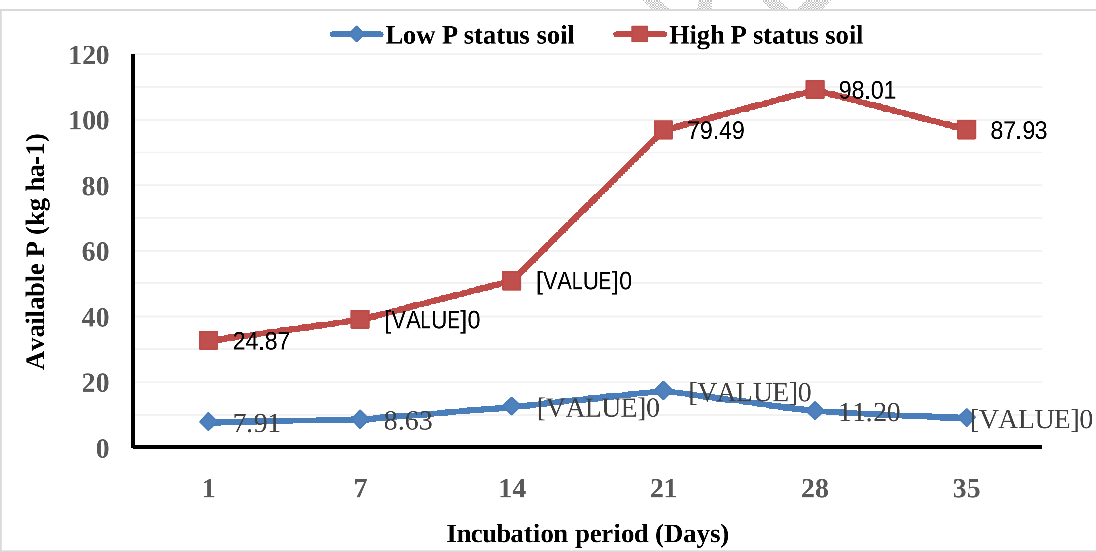

Figure 1: Release behavior of available P in low P and high P status soils at different days of incubation

3.2 Phosphorus fractions

In both the soils, the P content under different fractions varied withincubation intervals. Except organic-P (Org-P) fraction, allother P fractions *i.e.*saloid-P, aluminium-P (Al-P), iron-P (Fe-P), reductant soluble-P (Red-P), calcium-P (Ca-P) and total-P increased up to 28 DAI and thereafter showed declining trend in the content in both soils.

Saloid phosphorus: This form of P fraction was released early in the incubation period but in minimal amount compared to other P fractionsin both the soils. The content of Saloid P in both the soils ranged from 2.98 to 3.60 mg kg^{-1} in low P status soil and 4.20 to 6.55 mg kg^{-1}in high P status soil during 1 to 35 days of incubation. The magnitude of this fraction was continued to increase during the incubation and reached maximum value at 28 DAI in both low P (4.65 mg kg^{-1}) and high P (7.11 mg kg^{-1}) status soils and declined thereafter by the end of the incubation period *i.e.*upto 35 DAI in both the soils.By comparing, the content of this P fraction was higher in high P status soil than the low P status soil.The relatively higher content of SaloidP in high P status soil attributed to the transformation of P to Saloid-P due to higher clay content of high P status soil. The results were similar to the findings of Pant *et al.* (2017).

Al-P: The content of Al-P was comparatively higher in the high P status soil at all the days of incubation. The content of Al-P in high P status soil ranged from70.60 to 75.80 mg kg^{-1} and in low P statusit ranged from 25.83 to 27.84 mg kg^{-1} with increasing DAI from 1 to 35 days. In low as well as high P status soils, the Al-P content 1st increased from25.83 to 29.26mg $kg^{-1}$and 70.60 to 76.20 mg kg^{-1} , respectively with increasing DAI from 1 to 28 days and thereafter the content decreased to 27.84 in low P and 75.80 mg kg^{-1} in high P status soil. The higher magnitude of Al-P in high P status soil might be due to more content of Al in high P status soil which leads to more binding of phosphorus and this result was in agreement with the findings of Kumar *et al.* (2015).Daroub*et al.* (2000) also suggested that this fraction continued to rise over the course of incubation in three different soils where P get adsorbed into Al and Fe oxides-hydroxides or to precipitation of P compounds.

Iron phosphorus (Fe-P): The release of this fraction consistently increased upto 28 DAI in both the soils and its concentration in low P status soil fell in the range of24.1 to 28.40mg kg^{-1} and on later period of incubation *i.e.*upto 35 DAI, it declinedto 27.25 mg kg^{-1}. Similar trend was also observed inhigh P status soil where the range of Fe-P was found from42.15 to 49.64mg kg^{-1}upto 28 DAI and then declined to 47.10 mg kg^{-1} at 35DAI. However, in comparison to the low P status soil, high P status soil had larger concentration of this kind of fraction.Lair *et al.*, 2008 also reported similar results and found that Fe, Mn and Al were strongly associated with clay fraction and comparatively, less with the sand fraction.

Reductant Phosphorus (Red-P): This form of P, like the other forms of P mentioned above, also displayed similar patterns of increase and decrease throughout the incubation and maximum content of red-P was reached at 28 DAI and then declining in both soils by the end of incubation. Its concentration from 1 to 28 DAI fell in the range of 23.69 to 27.21 and 37.59 to 46.31 mg kg^{-1} in low P and high P status soils respectively and thereafter on further increase of incubation time upto 35 DAI the content of red-P get decreased from 27.21 to

26.88 mg kg^{-1}in low P status soil. As well as, its content was also get decreased in high P status soil from 46.31 to 45.60 mg kg^{-1} with the increase of incubation period upto 35 DAI. However, the content of red-P in all the days of incubation was found higher in high P status soil as compared to the low P status soil and the results were found similar with the findings of Ochwoh (2005) and Daroub*et al.* (2000).

Calcium phosphorus (Ca-P): The concentration of Ca-P differed in the two soils but followed the same trend in the release behavior. This form of P fraction accounted for the majority of the released P in both the type of soils.The concentration of this form of P in low P and high P status soil ranged from 100.73 -104.70 mg $kg^{-1}$and 158.75-163.85 mg kg^{-1}respectively.The release of Ca-P continued to increase during the incubation period but appeared to reached maximum at 28 DAIin both low P (106.59 mg kg^{-1}) and high P status soil (163.98 mg kg^{-1}) and slightly declined thereafter. It was observed from this study that among all the P fraction Ca-P was the dominant fraction in both the soil and its content was found larger in high P status soil as compared to low P status soil at all the days of incubation.This was in agreement to the findings ofGichangi (2009) and Daroub*et al.* (2000).A similar trend in the release of Ca-P was also observed by Pant *et al.* (2017) where they reported that Ca-P get increased consistently upto 30 DAI and declined thereafter at later days of incubation and the dominance of this fraction over other fraction might be due to the higher concentration of Ca-P in soils which then get solubilised by extracting with 0.5 N H_2SO_4 during its determination.

Organic bound phosphorus (Org-P): This form of org-Pgradually decreased from 43.36 to 27.64 mg kg^{-1} in low P and from 69.11 to 43.97 mg kg^{-1} in high P status soils with increasing incubation period up to 28 days andappeared maximum at 1 day of incubation in both the soils. Its decline,with the progress of incubation period corresponded with increase in quantity of other P fractions but with further increase of incubation time up to 35 days, it showed elevated values in both the soils and its concentration was increased in both low P (27.64- 31.97 mg kg^{-1}) and high P (43.97-47.86 mg kg^{-1}) status soils. However,like the other fractions, a similar pattern was appeared while comparing the amounts of org-P in the two soils and the content of this kind of P fraction was found to be more abundant in the high P status soilin contrast to the low P status soil. The higher content of org-P is associated with the amounts of organic compounds (Xavier *et al.*, 2009)

Total phosphorus (Total-P): The total P concentration in both the soils continued to increase with the incubation period and reached maximum at 28 DAI ranging from 220.69-224.45 mg kg^{-1} and 382.40-387.21 mg kg^{-1}in low and high P status soils, respectively.But its concentration in both the soils declined thereafter by the end of the incubation and its concentration was decreased from 224.45 to 222.24 mg kg^{-1} in low P status soil and 387.21 to 386.76 mg kg^{-1} high P status soil. The magnitude of the total P in high P status soil was higherin contrast to the other soil and this was due to the higher magnitude of other P fractions in high P status soil as compared to the low P status soil and also, this might be due to the differences in clay, organic carbon content and Fe and Al oxides which were higher in high P status soil, therefore, contributing to the higher concentration of total-P in high P status soil in comparison to the low P status soil.Daroub*et al.* (2000) also reported similar results.

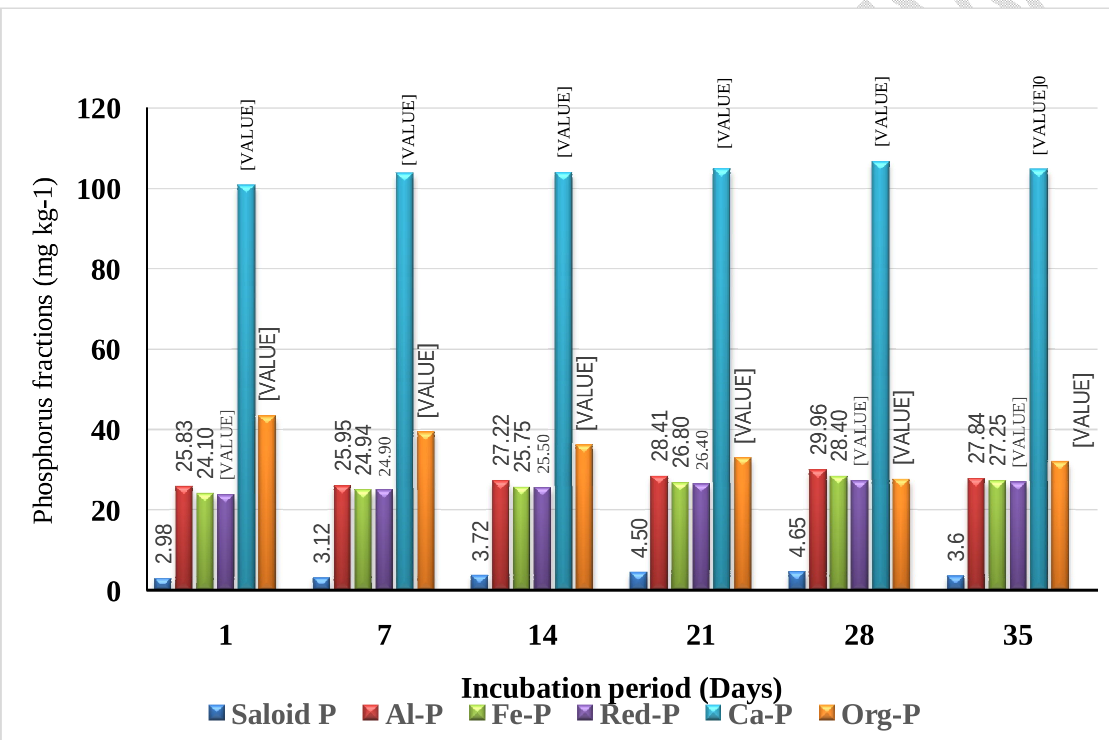

Figure 2: Distribution of P fractions in low P status soil at different days of incubation

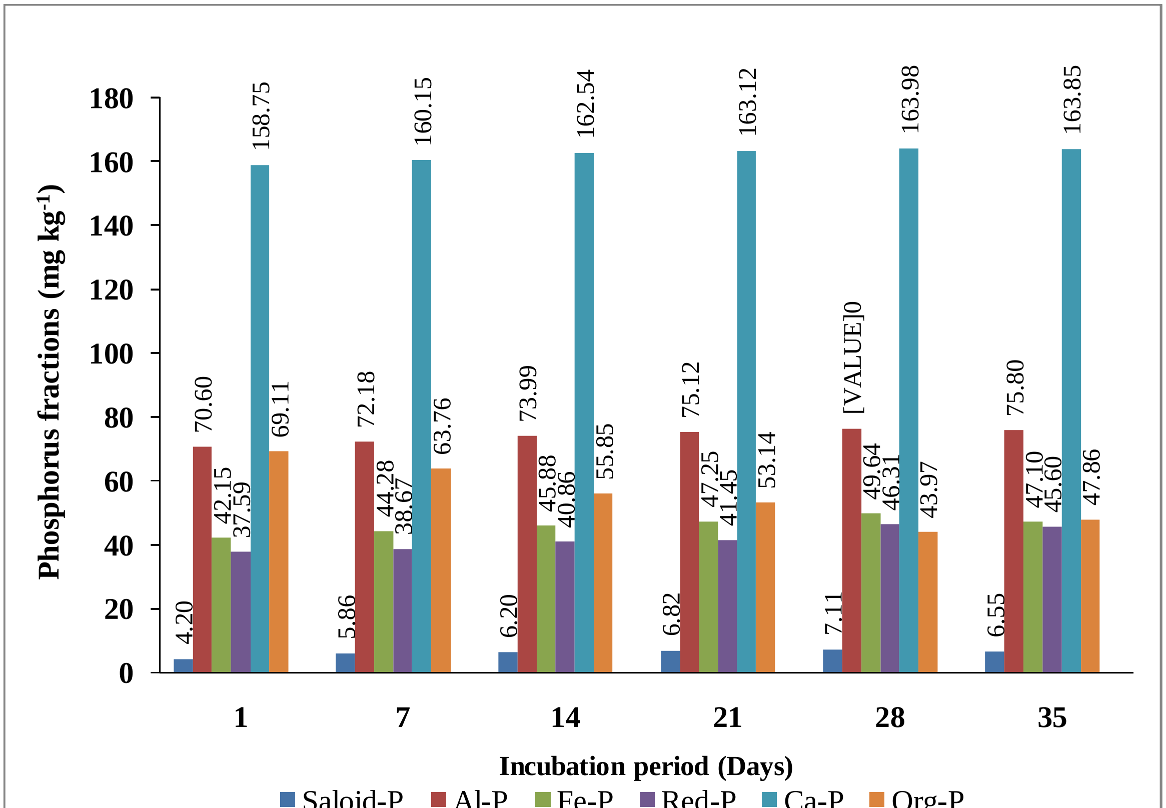

Figure 3: Distribution of P fractions in high P status soil at different days of incubation

Conclusion

It was observed that the release of available P was first increased up to 21 and 28 days in low and high P status soil, respectively. In both the soils,the release of differentforms of inorganic P showed similar trend. The release of different inorganic fractions increased up to 28 DAI and declined thereafter, with further increase in incubation period whereas the content of organic fraction in both the soil was more during initial days of incubation and consistently reduced with the progress of incubation time up to 28 days and increased by the end of incubation period. Thus, days of interval proved to be a significant factor in the release of availableP and different fractions of P and the release of P and its different fractions also depend on the soil texture as it was observed that content and release of available P and different P fractions were high in soil having high clay content and more native P. It was also noticed that among the P fractions in both the soils, Saloid P was released early in the incubation and Ca-P was found the most dominant fraction while Saloid-P was the least available P fraction.Also the distribution of various P fractions was found in following sequence Ca-P > Org-P > Al-P > Fe-P > Red-P >Saloid-P in both soils.

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