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## SOIL PHOSPHORUS FRACTIONATION IN CALCAREOUS SOIL AS AFFECTED BY ORGANIC AMENDMENTS APPLICATION

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*Abstract.* Understanding of P transformations following organic amendments addition to highly calcareous soils is necessary for developing better management practices that can help enhance P fertilizer use efficiency. Phosphorus solubility and availability for plant uptake under the conditions of arid calcareous soil is very low, making P nutrient supply a critical issue under these conditions. The aim of this study was to evaluate the impact of various types of organic amendments (chicken compost, cow compost and a mixture of humic-fulvic acid) applied alone at different rates of  $\text{KH}_2\text{PO}_4$  fertilizer on P fractions in calcareous soil using the sequential chemical extraction method. Amended calcareous soil was incubated under laboratory conditions and soil samples were collected at 0, 4, 8 and 16 weeks of the incubation periods. Soil was sequentially extracted and analyzed for P different fractions. The results indicated that the addition of chicken and cow compost increased soluble and exchangeable-P and Ca-P fractions in calcareous soil and the increases depend on application rates. The results indicated that combination of chicken and cow compost with different  $\text{KH}_2\text{PO}_4$  fertilizer application rates increased the concentration of soluble and exchangeable-P in the soil compared to organic amendments or  $\text{KH}_2\text{PO}_4$  fertilizer applied alone. The P associated with Ca was the dominant P fractions in soil, ranging between 51 to 59% regardless of the different treatment and the period of incubations. The Al- and Fe-associated P

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fractions varied between 2 and 9%, with the maximum value being observed at the eighth week of incubation. The residual-P fraction ranged between 5 and 22% at different incubation periods.

**Keywords:** changes in P fractions, mineral fertilizers, organic fertilizers, sequential fractionation, soils

## INTRODUCTION

Phosphorus (P) use efficiency and recovery is extremely low in agricultural soils of Saudi Arabia (Ahmad *et al.* 2018). This is related to the high content of free  $\text{CaCO}_3$  in those soils. After P fertilizer is added to a calcareous soil, P undergoes a series of chemical reactions with Ca to form Ca-associated P forms that are of low solubility and availability for plant (Alharbi *et al.* 2018). The soils of Saudi Arabia are also characterized by their very low content of organic matter and coarse texture, and those factors have a negative impact on P fertilizer use efficiency. The utilization of P by plants is generally very low due to the fixation and adsorption of P by soils (Al Harbi *et al.* 2013, Al-Rohily *et al.* 2013). This results sometimes in excessive use of P fertilizers with low P recovery. The main source of P fertilizers is via mining rock phosphate, a non-renewable resource whose reserve is subject to depletion under the current excessive use of P fertilizers. The global phosphate reserves range typically in the order of a few hundred years (Dawson and Hilton 2011, European Commission 2013). However, the good quality rock phosphate has been estimated to be depleted in the next 80 years if extraction continues at the current rate (Smil 2000). The decline in the quality of rock phosphate will cause the cost of P extraction to increase (Smil 2004).

The addition of organic manure not only provides additional sources of nutrients, but improves the soil physical and chemical conditions and may increase the efficiency of added P fertilizers (Zhu *et al.* 2018). Information on the availability of P following chemical fertilizer and compost application to the soil may improve the management of P fertilization (Al Harbi *et al.* 2013). Time is the major factor for P transformations in the soil and available P. For example, after the rapid decomposition of applied organic materials to the soil, the available P will increase, and more stable P fractions could remain in the soil. In a soil incubation study, Kashem *et al.* (2004) found that the application of swine manure caused an initial increase of the water-extractable P fraction, but after 16 weeks of incubation, the water-extractable P fraction decreased with the simultaneous increase of the P- $\text{NaHCO}_3$  fraction. Moreover, the application of cattle manure decreased available P, whereas other more stable P fractions increased, which suggests that microorganisms transformed inorganic available P into an organic form because of the higher amount of organic residue in the manure.

Information on the P availability following chemical fertilizer and organic fertilizer application to soil may improve the management of P fertilization.

Mahmoud *et al.* (2019) found that the application of biochar with inorganic P can be a promising strategy to improve soil productivity and soil quality in alkaline soil.

Application of organic amendments in combination with P fertilizers to calcareous soils of Saudi Arabia is not a common practice. Such studies on using local organic amendments to increase P solubility in calcareous soils receiving P fertilizers are needed. This can help better understand P transformations and solubility and therefore improve P fertilizer use efficiency under such conditions. Therefore, the objective of this study was to evaluate the effectiveness of the addition of chicken compost, cow compost, and mixture of humic-fulvic acids with different application rate of  $\text{KH}_2\text{PO}_4$  fertilizer on P fractions in calcareous soils. The effect of the period of incubation on the P species was also evaluated.

## MATERIALS AND METHODS

### *Soil sampling*

Soil samples was collected from the surface layers (0–30 cm) of calcareous soils located in the research center of King Saud University in Riyadh, Saudi Arabia. The soil samples were air-dried, ground, and sieved through a 2-mm sieve. Physical and chemical properties of the soil and P fractionation of the original soil are shown in Table 1.

### *Types of organic materials*

Three organic fertilizers were used to evaluate their effectiveness on P availability and changes in P fractions in calcareous soils. These organic fertilizers included chicken compost, cow compost, and a mixture of humic-fulvic acids with different application rates of chemical-P fertilizers. The chemical characteristics of these organic fertilizers are shown in Table 2.

### *Incubation study*

The incubation experiment was conducted at the Soil Science Department, College of Food and Agricultural Sciences, King Saud University, Saudi Arabia. The soil incubation experiment was conducted in glass jars with 300 g soil capacity. Chicken compost, cow compost, and a mixture of humic and fulvic acids with different application rates of chemical-P fertilizer were used (12 treatments) in a completely randomized design (CRD) with three replicates. The glass jars were incubated at 25°C and 70% of field capacity. Represented sub-soil samples were collected from each treatment at 0, 2, 4, 8, and 16 weeks after incubation and analyzed for P sequential fractionation.

Table 1. Physico-chemical properties of soil at the start of experiment

EC (dS m <sup>-1</sup> )	OM	CaCO <sub>3</sub> %	Cations			Anions			Available Nutrients					Particle Size Distribution			Texture Class						
			Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>-2</sup>	SO <sub>4</sub> <sup>-2</sup>	N	P	K	Fe	Zn	Cu		Mn	Sand	Silt	Clay		
8.403	50		0.27	43.5	19.7	11.0	3.20	0.44	11.4	0.50	0.00	23.1	4.80	2.60	56.5	2.78	0.32	0.17	1.15	70.3	16.0	13.7	Sandy loam
P fractionation of original soil (mg kg <sup>-1</sup> )																							
Soluble and exchangeable-P			Fe & Al-P			Ca-P			Residual-P					Total-P									
11.3			4.83			205			95.1					317									

Table 2. Initial chemical properties of organic amendments

Fertilizer type	pH	EC (dS m <sup>-1</sup> )	OM (%)	N			P			K			Fe			Zn			Cu			Mn			C:N
				1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5	1:5		
Cow compost	8.81	16.1	24.9	1.43	0.55	2.4	2599.0	213.2	97.6	204.90	11:1														
Chicken compost	6.25	20.1	50.1	1.71	1.49	2.0	1159.3	453.5	22.3	327.75	12:1														
Mixture of humic-fulvic acid	8.20	19.9	61.9	0.77	0.10	11.9	8287.6	21.3	34.5	9.39	43:1														

### *Sequential P fractionation*

A sequential P fractionation method reported by Hedley *et al.* (1982) with a slight modification, as described by Tiessen and Moir (1993) was used. Briefly, a 1.0 g soil sample was extracted with 25 mL of  $\text{NaHCO}_3$  0.50 M solution, shaken for 16 h, and centrifuged at 4000 rpm for 10 min to extract soluble and exchangeable-P, while the remaining soil sample was saved for subsequent extractions. The P bound to Al and Fe hydroxide minerals were extracted by adding 25 mL of 0.10 M NaOH solution to the soil sample from the previous extraction and shaken for 16 h. The solution was then centrifuged at 4000 rpm for 5 min and analyzed for Fe and Al phosphate. The Ca-bound P was extracted by adding 25 mL of 1.0 M HCl to the soil sample and shaken for 16 h. The supernatant was then centrifuged at 4000 rpm for 5 min and analyzed for Ca phosphate. The residual P was digested by adding 10 mL of concentrated  $\text{HNO}_3$  to the soil sample.

### *Statistical analysis*

Data were analyzed using SAS Version 9.4 (SAS Institute, 2013) and means were compared by Duncan's multiple range test (DMRT) with a 5% probability.

## RESULTS AND DISCUSSION

### *Properties of soil and organic fertilizers*

The physical and chemical properties of soils used in this study are listed in Table 1. The soil texture was sandy loam and the soil pH was 8.40 with EC of  $3.50 \text{ dS m}^{-1}$ . Additionally, the results indicated that the percentage of  $\text{CaCO}_3$  was relatively high, which is considered the most critical factor to fix P as calcium phosphate, which will not be available for plant uptake. As a result, sequential extraction of soil P significantly varied where the largest P fraction was Ca-P followed by soluble and exchangeable-P and Fe and Al-P (Table 1). Furthermore, Table 2 shows chemical characteristics of evaluated organic fertilizers. The results indicated that pH was 8.20, 6.30, and 8.80 for chicken compost, cow compost, and the mixture of humic and fulvic acid, respectively, and the percentage of organic matter (OM) content was 24.9, 50, and 61.9 for chicken compost, cow compost, and the mixture of humic and fulvic acid, respectively.

### *Influence of addition of organic fertilizers on P fractions*

The dissolution of organic fertilizers in soil had a significant impact on soil properties, including the soil pH and P fractions. Tables 3 and 4 show the effects of different treatments and incubation periods on P fractions, which include the soluble and exchangeable-P, Al and Fe-bound P, Ca-bound P, and residual-P as discussed below.

#### *Soluble and exchangeable-P*

Table 3 shows P fractions as influenced by organic fertilizers with different rates of  $\text{KH}_2\text{PO}_4$  fertilizer, as well as different times of incubation. At zero time of incubation, the treatment of cow compost (10 g) with  $\text{KH}_2\text{PO}_4$  fertilizer (100 g) and  $\text{KH}_2\text{PO}_4$  fertilizer (300 g) exhibited the highest concentration of soluble and exchangeable-P extracted by  $\text{NaHCO}_3$  compared to that of the control treatment. Furthermore, the 2<sup>nd</sup> highest concentration of soluble and exchangeable-P was observed for the treatment of chicken compost (10 g) and chicken compost (10 g) with  $\text{KH}_2\text{PO}_4$  fertilizer (100 g) compared to that of other treatments. Similar results were obtained at 4 weeks of incubation when the highest concentration of soluble and exchangeable-P was recorded for chicken compost (10 g  $\text{kg}^{-1}$ ) with  $\text{KH}_2\text{PO}_4$  fertilizer (300 g) compared to that of the control treatment, whereas there were no significant differences among the chicken compost (10 g  $\text{kg}^{-1}$ ), the  $\text{KH}_2\text{PO}_4$  fertilizer (100 mg P  $\text{kg}^{-1}$ ), and the  $\text{KH}_2\text{PO}_4$  fertilizer (300 mg P  $\text{kg}^{-1}$ ). At 8 weeks of incubation, the treatments of cow compost (10 g  $\text{kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer (300 mg P  $\text{kg}^{-1}$ ) and chicken compost (10 g  $\text{kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer (300 mg P  $\text{kg}^{-1}$ ) had the highest concentration of soluble and exchangeable-P compared to that of the control treatment. At 16 weeks of incubation, there were significant differences between organic fertilizers; the highest concentrations of soluble and exchangeable-P were recorded for the cow compost (10 g  $\text{kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer (300 mg P  $\text{kg}^{-1}$ ) treatment.

On the other hand, Fig. 1 shows the proportions of P fractions during different incubation periods. The results showed that the addition of organic fertilizers increased the concentration of soluble and exchangeable-P. This increase is caused by the decomposition of organic materials, which produced organic acids that could solubilize and release P from insoluble phosphate minerals and reduce the P adsorption to soil particles. This is consequently expected to increase P availability in the soil, whereas decomposed organic matter has been reported to decrease P adsorption and enhance P availability (Sánchez-de Prager and Cisneros-Rojas 2017); therefore, application of organic fertilizers with  $\text{KH}_2\text{PO}_4$  fertilizer may be a promising management option to enhance the availability and solubility of applied P fertilizers. These results are consistent with those of another study, which confirmed that applying organic materials

Table 3. P fractions (mg kg<sup>-1</sup>) as influenced by organic fertilizers with different application rates of KH<sub>2</sub>PO<sub>4</sub> fertilizer at different incubation times

Treatments		Soluble and exchangeable P	Fe and Al-P	Ca-P	Residual-P	Total-P
<b>Zero time</b>						
Control		13.3 g	2.49 e	199 c	49.2 fe	264
Cow compost (10 g kg <sup>-1</sup> )		49.6 f	4.78 ed	198 c	42.7 f	295
Chicken compost (10 g kg <sup>-1</sup> )		87.5e	12.9 cb	209 c	50.9 fce	360
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> )		11.9 g	2.67 e	200 c	57.9 cb	272
KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		128 d	5.01 ed	221 c	60.1 cb	414
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		128 d	9.99 cd	203 c	52.6 ce	394
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		153 c	15.0 b	248 b	59.3 cb	476
KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		203 a	5.65 ed	262 b	55.3 cb	526
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		198 a	8.75 cd	255 b	52.1 fc	515
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		180 b	20.6 a	307 a	107.2 a	615
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		89.3e	7.58 ed	207 c	43.5 fe	347
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		190 ab	5.00 ed	268 b	61.2 b	525
<b>4 weeks</b>						
Control		10.3 g	1.69 g	204 d	19.0c	235
Cow compost (10 g kg <sup>-1</sup> )		31.5 fg	6.54 e	203 d	26.2c	267
Chicken compost (10 g kg <sup>-1</sup> )		50.0 fe	22.2 c	232 bc	51.0cb	355
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> )		9.56 g	2.76 fg	204 d	19.5c	236
KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		65.7 fe	5.60 fe	220 cd	55.2cb	346
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		126 d	14.0 d	214 cd	20.7c	374
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		169 c	30.2 b	278 a	90.3b	568
KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		184 c	8.38 e	241 bc	22.8c	456
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		237 b	30.4 b	237 bc	27.0c	531
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		301 a	45.3 a	236 bc	60.6cb	642
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )		73.6 e	7.99 e	221 cd	143a	445
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )		165c	8.67e	262b a	28.6c	465

Table 3. **Continued**; P fractions (mg kg<sup>-1</sup>) as influenced by organic fertilizers with different application rates of KH<sub>2</sub>PO<sub>4</sub> fertilizer at different incubation times

Treatments	Soluble and exchangeable P					Total-P
	Fe & Al-P	Ca-P	Residual-P			
	<b>8 weeks</b>					
Control	12.4 f	205 f	95.1 b			317
Cow compost (10 g kg <sup>-1</sup> )	30.0 ef	203 f	96.8 b			343
Chicken compost (10 g kg <sup>-1</sup> )	64.2 d	254 cb	116 ba			481
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> )	13.7 f	193 f	56.8 c			266
KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	54.9 ed	230 ed	60.3 c			362
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	112 c	222 e	65.4 c			487
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	101 c	242 cd	117 ba			523
KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	190 b	285 a	95.1 b			587
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	247 a	245 cb	67.3 c			647
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	233 a	261 b	128 a			739
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	59.8 ed	229 ed	58.3 c			360
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	161 b	284 a	69.4 c			527
	<b>16 weeks</b>					
Control	11.3 g	200 f	102 bc			317
Cow compost (10 g kg <sup>-1</sup> )	34.3 f	211 e	56.5 e			314
Chicken compost (10 g kg <sup>-1</sup> )	35.6 f	222 d	86.4 dc			360
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> )	7.25 g	198 f	91.6 dc			300
KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	60.1 e	241 b	84.2 d			392
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	95.0 d	236 d	87.0 dc			467
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	91.1 d	237 cb	116 b a			500
KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	131 c	262 a	113 b a			513
Cow compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	243 a	231 cd	91.8 dc			627
Chicken compost (10 g kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	231 b	264 a	121 a			704
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (100 mg P kg <sup>-1</sup> )	57.8 e	227 cd	103 bc			394
Mixture of humic-fulvic acid (24 mg kg <sup>-1</sup> ) + KH <sub>2</sub> PO <sub>4</sub> (300 mg P kg <sup>-1</sup> )	129 c	267 a	124 a			533

Note: Values within a column followed by the same letter do not differ significantly ( $p > 0.05$ ) according to Duncan's Multiple Range Test



Table 4. Pearson's correlation coefficient between P fractions in soil

P fractions	Time	Soluble and exchangeable-P	Fe & Al-P	Ca-P	Residual-P	Soil pH
Soluble and exchangeable-P	NS					
Fe and Al-P	0.278**	0.494**				
Ca-P	NS	0.484**	NS			
Residual-P	0.502**	NS	0.329**	NS		
Soil pH	-0.650**	NS	-0.280**	NS	-0.303**	
Organic carbon	NS	0.312**	0.410**	NS	NS	NS

\*\* significant at the 0.01 level; NS – not significant.

increased the concentration of soluble and exchangeable-P as the incubation time increased (Yu *et al.* 2013). These results are also in agreement with the findings of Kashem *et al.* (2004), who documented that the concentration of the P fractions extracted by  $\text{NaHCO}_3$  increased with increasing incubation time.

### *Al-Fe bound P*

Table 3 shows that there were significant differences between organic fertilizers and the concentration of Al-Fe bound P extracted by NaOH. At zero time of incubation, the maximum concentration of Al-Fe bound P was observed in the chicken compost ( $10 \text{ g kg}^{-1}$ ) and  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) treatment compared to the control treatment. Likewise, at 4 weeks of incubation, the chicken compost ( $10 \text{ g kg}^{-1}$ ) and  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) treatment had the highest concentration of Al-Fe associated with P. Similar results were obtained at 16 weeks of incubation when the highest concentration was recorded for the chicken compost ( $10 \text{ g kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) treatment.

Otherwise, Fig. 1 shows the ratio of Al-Fe bound P during different incubation periods; the results demonstrated that the ratio of this P fractions ranged from 2 to 8% of total P, regardless of the treatment or incubation periods. The results indicated that the amounts of the Al-Fe P fractions were very low compared to other P fractions. This was likely caused by the high original concentration of Ca ions in the soil, which was responsible for determining the ion speciation in the soil solution (Bohn *et al.* 2001). Moreover, the high concentration of  $\text{CaCO}_3$  is broadly known to be the critical factor to fix P as Ca-phosphate as observed in this study.

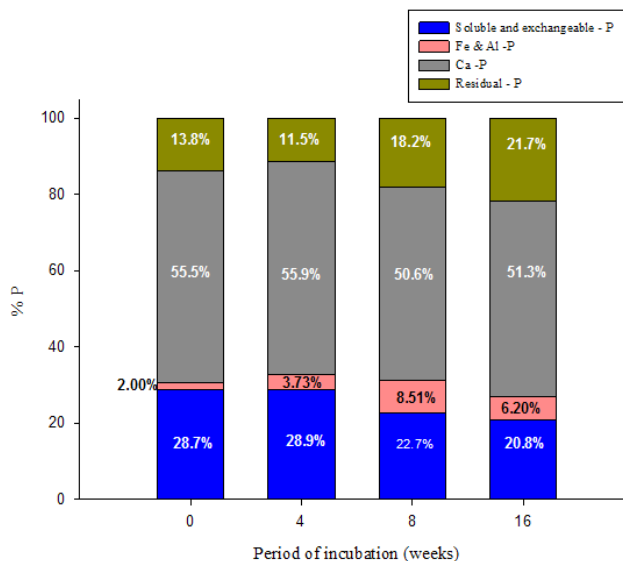


Fig. 1. Percentage of different P fractions during incubation periods

### *Ca-bound P*

The results of this study showed significant effects of organic fertilizers on Ca-bound P, which is considered highly insoluble for plant uptake and has been documented to be the dominant P fraction in calcareous soil (Shen *et al.* 2004). As is shown in Table 3, Ca-bound P was the highest concentration at zero-time of incubation for the chicken compost (10 g kg<sup>-1</sup>) and KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg kg<sup>-1</sup>) treatment. Additionally, at 4 weeks of incubation, the chicken compost (10 g kg<sup>-1</sup>) + KH<sub>2</sub>PO<sub>4</sub> fertilizer (100 mg kg<sup>-1</sup>) treatment produced the highest concentration of Ca-bound P with a concentration of 278 mg kg<sup>-1</sup>, whereas the control treatment produced the lowest concentration. While, at 8 weeks of incubation, Ca-bound P had the highest concentration in the KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) treatment followed by the chicken compost (10 g kg<sup>-1</sup>) + KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) treatment with concentrations of 285 and 261 mg kg<sup>-1</sup>, respectively. The same results were obtained at 16 weeks of incubation, when the highest concentration of Ca-bound P was recorded for the KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) and chicken compost (10 g kg<sup>-1</sup>) + KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) treatments. Regarding the percentage of P fractions listed in Fig. 1, Ca-bound P is the most common P fraction, ranging from 50 to 58% of total-P, regardless of other treatments or incubation periods. The maximum percentage of Ca-P was observed in comparison with other P fractions, which resulted in the highest concentration of CaCO<sub>3</sub> under the conditions of this experiment. This supports the earlier observations that most Saudi Arabia soils are dominated by the Ca-P fraction (Alharbi *et al.* 2018, Rohily *et al.* 2019). However, the ratio of this P fractions slightly decreased after 8 and 16 weeks of incubation. This decrease was caused by the decomposition of the added organic materials that could have produced organic acids and regulated the soil pH.

### *Residual-P*

Table 3 presents the concentration of residual-P at the different incubation periods as affected by organic fertilizers with varying rates of KH<sub>2</sub>PO<sub>4</sub> fertilizer. At zero time of incubation, the residual-P was at its highest concentration for the chicken compost (10 g kg<sup>-1</sup>) with KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) treatment with a concentration of 107 mg kg<sup>-1</sup>, whereas the treatment of cow compost (10 g kg<sup>-1</sup>) produced the lowest concentration compared to that of other treatments. At 4 weeks of incubation, the highest concentration of residual-P was recorded for the mixture of humic and fulvic acid (24 mg kg<sup>-1</sup>) + KH<sub>2</sub>PO<sub>4</sub> fertilizer (300 mg P kg<sup>-1</sup>) followed by the chicken compost (10 g kg<sup>-1</sup>) + KH<sub>2</sub>PO<sub>4</sub> fertilizer (100 mg P kg<sup>-1</sup>) treatment; however, there were no significant differences among the mixture of humic and fulvic acid (24 mg kg<sup>-1</sup>), cow compost (10 g kg<sup>-1</sup>), and cow compost (10 g kg<sup>-1</sup>) with KH<sub>2</sub>PO<sub>4</sub> fertilizer (100 and 300 mg P kg<sup>-1</sup>)

treatments compared to that of the control treatment. However, at 8 weeks of incubation, the chicken compost ( $10 \text{ g kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) treatment had the highest concentration of residual-P with a concentration of  $128 \text{ mg kg}^{-1}$ ; however, there were no significant differences between the chicken compost ( $10 \text{ g kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer ( $100$  and  $300 \text{ mg P kg}^{-1}$ ) and chicken compost ( $10 \text{ g kg}^{-1}$ ) treatments. Similar results were obtained at 16 weeks of incubation when the highest concentration of residual-P was recorded for the chicken compost ( $10 \text{ g kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) treatment with a concentration of  $121 \text{ mg kg}^{-1}$ . This observation indicated that chicken compost had significant superiority over cow compost. On the other hand, the percentage of residual-P fraction shown in Fig. 1, as expected, responded differently with different incubation times. The residual-P fraction ranged from 14 to 22% of total-P and increased with incubation time. The results also indicated that the percentage of residual-P fraction was the 3<sup>rd</sup> most dominant P fractions after the percentage of soluble and exchangeable-P and Ca-P fractions.

Additionally, the results showed a highly significant effect between the residual-P fraction and P associated with Fe and Al-P (Table 4). This observation is consistent with other findings reported by Solomon *et al.* (2002), in which there was a significant correlation between the ratio of residual-P and P associated with Al and Fe oxides.

### *Total-P*

The concentration of total-P ranged from  $232 \text{ mg P kg}^{-1}$  to  $739 \text{ mg P kg}^{-1}$  soil and the solitary addition of chicken compost or cow compost in combination with  $\text{KH}_2\text{PO}_4$  fertilizer increased the concentration of total-P (Table 3). The addition of cow compost or chicken compost resulted in the increase of most of the different P forms in the soil compared to the control treatment. Chicken compost ( $10 \text{ g kg}^{-1}$ ) +  $\text{KH}_2\text{PO}_4$  fertilizer ( $300 \text{ mg P kg}^{-1}$ ) recorded the highest concentration of total-P compared to other different treatments.

## CONCLUSIONS

The results revealed that the addition of chicken and cow compost dramatically increased different P fractions in calcareous soil and the increase was dependent on the type of organic fertilizer and application rate of  $\text{KH}_2\text{PO}_4$  fertilizer. The soluble and exchangeable-P, Ca-occluded P fraction, and residual-P fractions were the most dominant P forms. The results also indicated that there were significant differences between the effects of different P treatments and periods of incubation on soluble and exchangeable-P, Ca-occluded P fraction, residual-P fraction, Fe and Al-occluded P fraction, and total-P. There was no significant difference

between the addition of cow or chicken compost with  $\text{KH}_2\text{PO}_4$  fertilizer at the rate of  $300 \text{ mg P kg}^{-1}$  soil. We recommend the addition of only  $100 \text{ mg P kg}^{-1}$  soil as  $\text{KH}_2\text{PO}_4$  fertilizer with cow compost or chicken compost.

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**Conflict of interest:** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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