Availability and Transformations of Phosphorus in Calcareous Sandy Soil as Affected by Farmyard Manure and Elemental Sulfur Applications

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ABSTRACT

An incubation experiment was conducted to study the effects of farmyard manure (FYM) and elemental sulfur (S) on availability, fractionation and transformation of phosphorus in calcareous sandy soil. Soil samples were treated with FYM at levels: 0 (FYM_0), 2.5 (FYM_1), 5 (FYM_2) and 7.5 (FYM_3) g pot^{-1} and S at levels: 0 (S_0), 0.1 (S_1), 0.2 (S_2) and 0.3 (S_3) g pot^{-1}. The soil was incubated for ten weeks under field capacity conditions. Additions of FYM caused significant increases in the amount of available P (Olsen−P) from 34.57 to 44.54 mg kg^{-1}. The S with FYM application significantly increased Olsen−P of this soil at S_1FYM_1 from 42.95 to 52.70 mg kg^{-1}. Significant reduction in Olsen−P was observed at S_2 and S_3 levels, but the addition of S at S_1 level led to its insignificant increase. FYM application transformed HCl-Pi, NaOH II-Pi and residual P to NH_4Cl-P, $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Pi, NaOH I-Po and NaOH II-Po fractions. Application of S converted the NH_4Cl-P, NaOH I-Pi and HCl-Pi fractions to $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Po, NaOH II-Pi, NaOH II-Po and residual P fractions. It's recommended adding FYM to calcareous sandy soils as well as adding S combined with FYM to improve the soil properties.

Keywords: Incubation; Labile-P; Olsen-P; Phosphorus fractions

INTRODUCTION

Calcareous sandy soils are common in many areas around the world specially arid and semiarid regions, that suffer from scarcity of most nutrients availability particularly phosphorus. Many soils in their natural state do not contain adequate amount of available P to maximize crop yield (Hopkins and Ellsworth, 2005). Phosphorus availability in soils is affected by several factors such as soil reaction, organic matter, texture (Verma, 2013), calcium carbonate (Hopkins and Ellsworth 2005), parent material, weathering and climatic conditions (Fuentes et al. 2008). Moreover, phosphorus availability in calcareous soils is influenced by many factors as size and amount of free $CaCO_3$, activity of Ca^{+2} ions as well as amount of clay (Sims and Ellis, 1983; Tisdale et al., 1997). In calcareous soils, interaction of soluble phosphate from adding mineral phosphate fertilizers and soil Ca ions occurs and produces dicalcium phosphate which with time transforms to tricalcium phosphate as well as phosphorus adsorbed on calcite surfaces, leading to decrease in solubility and availability of soil phosphorus (Brady and Weil, 1999; Delgado and Torrent, 2000; Leytem and Mikkelsen, 2005). Amelioration of P availability and uptake by plants is important for economic, humanitarian and environmental reasons (Vance et al., 2003). The suitability extent of calcareous soils for agriculture depends on management systems via adding of organic materials and some amendments to improve availability of nutrients, particularly phosphorus (Al-Oud, 2011; Karimi et al., 2012). Applied municipal compost to some calcareous soils was reported to increase soil phosphorus availability (Hosseinpur et al., 2012). Organic manure additions also caused an increment in Olsen extractable P of soil (Bahl and Toor, 2002). In P-fixing soils, applications of organic matter were reported to increase available P because of mineralization (Iyamuremye and Dick, 1996). The oxidation of sulfur in the calcareous soils is influenced by many factors like particle size of sulfur, soil moisture, temperature, pH, nutrient status and microbial activity of the soils as well as the oxidation of sulfur is rapid under low soil pH conditions (Havlin et al., 1999). Oxidation of sulfur in the soil is achieved by certain groups of some microorganisms as acidophilic bacteria, especially *Thiobacillus spp.* (Seidel et al., 1998; Kayser et al., 2000). Elemental sulfur additions to calcareous soil caused decrease soil pH and increase in Olsen extractable phosphorous (Modaihsh et al., 1989). Phosphorus fractions were categorized into three groups are labile P includes NH_4-Cl and $NaHCO_3$-P (Pi and Po); moderately labile P contains NaOH-P (Pi and Po) and HCl-Pi; stable P or non labile was (NaOH II-Pi, NaOH II-Po and residual P) according to (Niederberger et al., 2015). Phosphorus fractions may vary in mobility, bioavailability and chemical behavior and can be transformed under certain conditions (Jalali and Ranjbar, 2010). Generally, manure application has important dynamic effects on chemical fractions of phosphorus because P released from manure is gradually converted into available forms by the time (Halajnia et al., 2009). It is well known that the addition of phosphate fertilizers to calcareous soils happen phosphorus may turn into insoluble forms which are

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unavailable to plants. So, the objectives of the current study were to assess the effects of adding farmyard manure, elemental sulfur or both to calcareous sandy soil on (1) soil pH, (2) phosphorus availability, (3) changes of phosphorus fractions, and (4) transformations of phosphorus forms from non-labile P (stable P) to labile P.

MATERIALS AND METHODS

Incubation experiment: An incubation experiment was conducted, during January 2014, to study the effects of farmyard manure (FYM) and elemental sulfur (S) as well as inoculation with *Thiobacillus* bacteria on the availability and transformations of phosphorus in calcareous sandy soil. Soil sample at 0-30 cm depth was collected from El-Ghorieb Experimental Station Farm, Assiut University, Assiut, Egypt. This soil was classified according to U.S. Soil Taxonomy as Entisols; Typic Torripsamments.. Table 1 shows some physical and chemical properties of this soil and farmyard manure. The collected soil samples were air dried, crushed, and passed through 2 mm sieve. Plastic pots (7.5 cm in height and 10.5 cm in diameter at the top and 8.7 cm at the base) containing 500 g calcareous sandy soil were used in this experiment. Superphosphate fertilizer (15.5% P_2O_5) at level 0.15 g was added to each pot (equivalent to 720 kg ha^{-1}). Farmyard manure (FYM) was air-dried, crushed, and passed through 2 mm sieve. Then, it was added and mixed with soil in each pot at level of 0 (FYM_0), 2.5 (FYM_1), 5 (FYM_2) and 7.5 (FYM_3) g pot^{-1} (equivalent to 0, 12, 24 and 36 ton ha^{-1}). At that time, elemental sulfur (S) was added to the soil in each pot at levels of 0 (S_0), 0.1 (S_1), 0.2 (S_2) and 0.3 (S_3) g pot^{-1} (equivalent to 0, 480, 960 and 1440 kg ha^{-1}) as fine granules and mixed with soil that was inoculated with *Thiobacillus* bacteria which was added to the pots in liquid form. Experimental design was randomized complete block with factorial arrangement of treatments with three replications. Each pot was left at the same place during period of incubation in the laboratory at room temperature for ten weeks with keeping moisture content at field capacity. After incubation, soil sample was taken from each pot and air-dried, crushed, passed through 2 mm sieve and kept for analysis.

Chemical analysis: Available phosphorus in soil samples was extracted using 0.5 M $NaHCO_3$ of pH 8.5 according to Olsen et al. (1954). Phosphorus sequential fractionation of soil samples was performed according to the methods described by Hedley et al. (1982) and modified by Chen et al. (2000) as shown in Fig. 1. In these methods, 1 g soil was subjected to sequential fractionation. The phosphorus in $NaHCO_3$ and NaOH supernatants were digested by potassium persulfate in order to determine its total content of P (Pi+Po), a calculation of Po was then made as described by Bowman (1989). Residual P was calculated as difference between total P and sum of different fractions (Frossard et al., 1989). Phosphorus in the extracts was measured colormetrically by chlorostannous phosphomolybdic acid method in sulphuric acid system (Jackson, 1973).

Statistical analysis: Data were analyzed by standard ANOVA procedure and significance was always based on $P \leq 0.05$ level using Duncan's Multiple Range Test. Statistical analysis in this experiment was done by using MSTAT program according to Steel and Torrie (1982).

Table 1. Physico-chemical properties of the experimental soil and farmyard manure

Property	**Value**
Soil	
Particle size Distribution	
Clay (%)	6.8
Silt (%)	6.4
Sand (%)	86.8
Texture	Loamy sand
Field capacity (% w/w)	10.77
Organic carbon (g kg^{-1})	6.9
$CaCO_3$ (g kg^{-1})	249.5
pH (1: 1)	7.55
Available P (mg kg^{-1})	24.32
Farmyard manure	
Organic carbon (g kg^{-1})	134.5
pH (1: 1)	8.52
Total P (mg kg^{-1})	1202.99

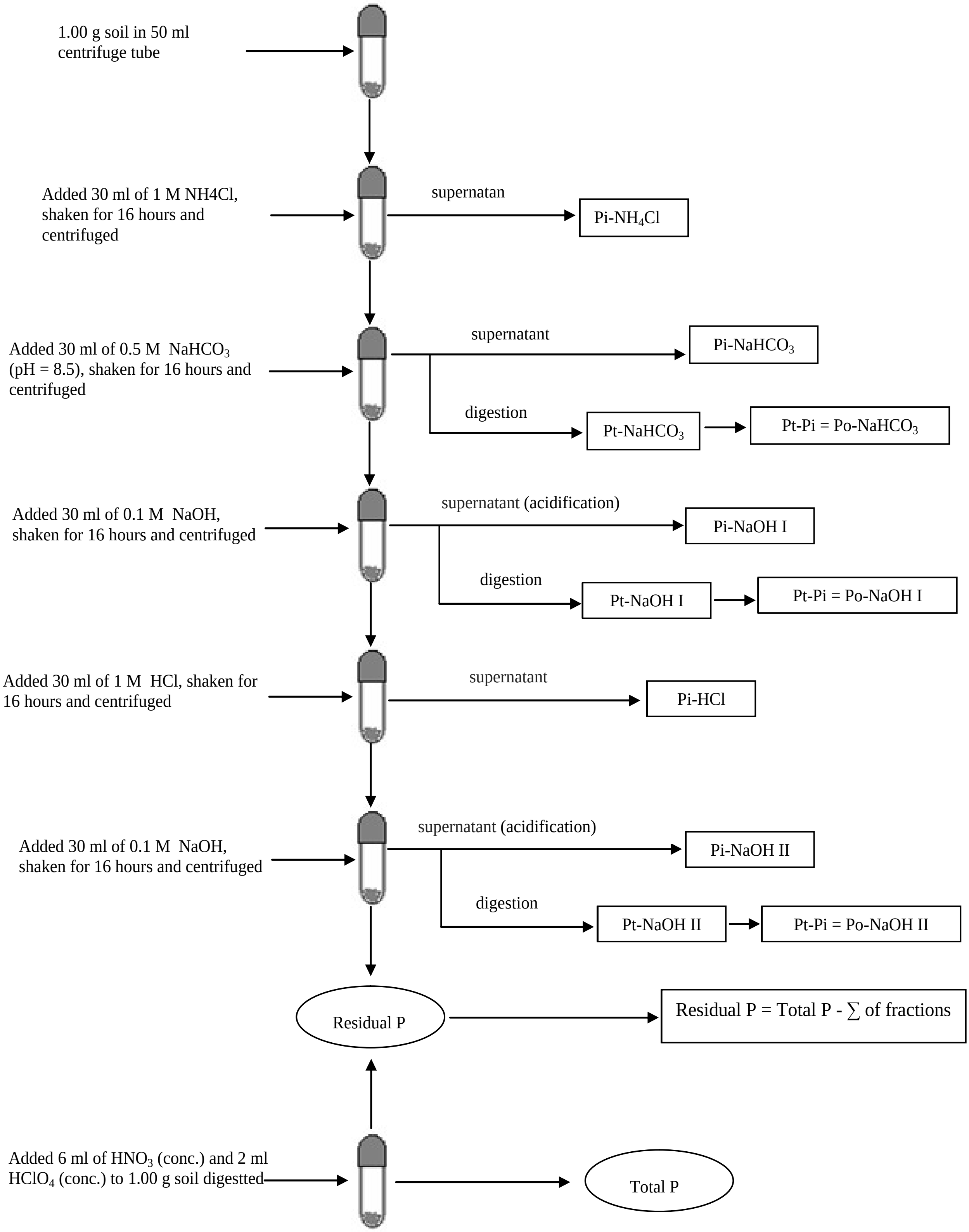

Figure 1. Sequential fractionation of soil phosphorus according to Hedley et al. (1982) modificated by Chen et al. (2000)

RESULTS AND DISCUSSION

Farmyard manure application

Available and total phosphorus: Incubating farmyard manure with calcareous sandy soil for ten weeks resulted in significant increases (*$P \leq 0.05$*) of available phosphorus in soil from 34.57 mg kg^{-1} of (FYM_0) to 44.54 mg kg^{-1} with adding the highest level of farmyard manure (Table 2). Farmyard manure addition to calcareous sandy soil led to a significant increase in total soil phosphorus compared to FYM_0 treatment (Table 2). Treating this soil with FYM increased total P from 440.97 mg kg^{-1} (FYM_0) to 479.39 mg kg^{-1} at the highest level of farmyard manure (FYM_3). From the results of this study, we conclude that the available phosphorus after an incubation period increased in calcareous sandy soil by using farmyard manure fertilization. The application of farmyard manure to the calcareous sandy soil at high level caused relative increases in the available phosphorus by 28.8 % compared to the control. Phosphorus availability in soil increased when phosphorus released from organic matter during the mineralization process (Iyamuremye and Dick, 1996; Verma et al., 2005). The available phosphorus in calcareous sandy soil at Assiut governorate, Egypt, which treated with farmyard manure significantly improved, the addition of FYM to this soil raised the available P from 11.91 to 16.68 mg kg^{-1} (Badawy et al., 2011). Al-Oud (2011) indicated that the availability of phosphorus was significantly increased from 4.65 to 33.72 mg kg^{-1} at treating rock phosphate in calcareous soil in Saudi Arabia by different rates of organic manure. The total P increased with fertilization of the calcareous sandy soil by FYM. Applying FYM at highest level to the calcareous sandy soil added about 38.42 mg kg^{-1} of phosphorus for the total phosphorus in the control treatment. The organic matter is considered a source of nutrients; it is expected to add phosphorus to soil and increase total content of phosphorus. Manure application increased total soil phosphorus (Qian and Schoenau, 2000).

Phosphorus fractions

Labile fractions: The results showed a significant increase in phosphorus extracted by NH_4Cl (NH_4Cl-P) with adding farmyard manure to calcareous sandy soil (Table 2). Farmyard manure application to calcareous sandy soil raised NH_4Cl-P from 29.00 mg kg^{-1} at FYM_0 to 39.81 mg kg^{-1} at FYM_3. Incubation of FYM with calcareous sandy soil led to significant increment in $NaHCO_3$-Pi and $NaHCO_3$-Po fractions (Table 2). This enhanced soil inorganic Phosphorus fraction extracted by $NaHCO_3$ which ranged from 72.14 to 88.42 mg kg^{-1} with increasing farmyard manure supply. Moreover, application of FYM to calcareous sandy soil resulted in an increase in $NaHCO_3$-Po from 54.16 to 80.33 mg kg^{-1} with increasing farmyard manure supply. The response of easily available NH_4Cl-P was noticed at FYM applications. The highest concentration of NH_4Cl-P was observed in FYM_3 treatment. NH_4Cl−P accounted about 6.6 % of total P for control and 8.3 % at the highest level of FYM in the soil after 10 weeks incubation. The additions of sewage sludge and chicken litter to the soil increased the NH_4Cl extracted phosphorous (Kalembasa and Kuziemska, 2007). The $NaHCO_3$-Pi and $NaHCO_3$-Po fractions reacted strongly and rapidly to FYM applications because the addition of phosphorus via fertilization by FYM. The concentration of $NaHCO_3$-Pi and $NaHCO_3$-Po fractions in this soil gradually increases with increasing FYM levels and the highest concentrations of $NaHCO_3$-Pi and $NaHCO_3$-Po fractions were found at the highest level of fertilization by FYM. Several studies found that the additions of organic amendments such as compost (Scherer and Sharma, 2002) and manure (Qian and Schoenau, 2000) to the soil increased the $NaHCO_3$-Pi fraction. Poultry manure was applied combination with superphosphate led to increasing organic P after 4 weeks, but decrease at 6 weeks when poultry manure was applied alone (Ojo et al., 2014).

Moderately labile fractions: NaOH I-Pi fraction significantly increased with FYM additions to calcareous sandy soil at FYM_1 level. FYM application to calcareous sandy soil resulted in an increasing NaOH-Pi from 17.36 to 20.68 mg kg^{-1} with using FYM_1 level. NaOH I-Po fraction significantly increased with the FYM addition to calcareous sandy soil (Table 2). Increase in NaOH I-Po of this soil due to FYM was from 19.22 at control treatment to 33.28 mg kg^{-1} at the highest level of farmyard manure. Incubation with farmyard manure along with calcareous sandy soil led to decline in HCl-Pi from 159.50 to 153.16 mg kg^{-1} with using FYM_3 treatment (Table 2). Addition of steer manure and alfalfa residues to soils also showed increases of NaOH I-Pi fraction (Iyamuremye et al., 1996). The concentration of labile Po in the soil was reported to increase with the application of manure (Yin and Liang, 2013). Addition of liquid swine manure to soil was found to raise NaOH I-Po fraction after 16 weeks of incubation (Qian and Schoenau, 2000). The moderately labile Po fraction increment with fertilized the soil by manure (Yin and Liang, 2013). In spite of the applied FYM was non−significant on HCl-P fraction, the HCl-P fraction accounted for a higher percentage of the total P (36.2 to 31.9 %) than all fractions. The soil fertilized with FYM the percentages of HCl-P fraction reduced from 36.2 to 31.9 %. The results showed that in soil under study the major proportion of P was associated with Ca. Liquid swine manure additions to soil non significantly decreased HCl-Pi fraction after 16 weeks of incubation (Qian and Schoenau, 2000). Steer manure application or lime to some soils caused no significant changes in HCl-Pi fraction (Iyamuremye et al., 1996). However, Sui et al. (1999) found reduction in HCl-Pi fraction with adding biosolids to soil. On the other hand, some researchers found that addition of manure to soil raised phosphorus concentrations associated with calcium (Yin and Liang, 2013).

Stable fractions: Farmyard manure application to this soil increased NaOH II-Po fraction (Table 2). The addition of farmyard manure to this soil resulted in increasing NaOH II-Po fraction from 2.46 mg kg^{-1} (FYM_0) to 4.37 mg kg^{-1} at (FYM_2). NaOH II-Po fraction increases slightly because FYM applied. The highest concentration NaOH II-Po observed in FYM_2 treatment. The phosphorus was less abundant P fraction of this soil and constituting between 0.9% and 1.3% of the total P. The results obtained from this experiment also showed a significant decrease in residual P fraction with FYM as compared to control treatment (Table 2). The addition of farmyard manure at level FYM_3 to this soil led to a reduction in residual P from 70.46 to 47.73 mg kg^{-1}. Reduced amounts of residual P fraction due to FYM additions to this soil may be transformed to other P fractions, especially $NaHCO_3$-Pi and NH_4Cl-P. Generally, the concentration of P in residual fraction tended to decrease with treating calcareous sandy soil by FYM under incubation, indicating former fractions served as a primary sink for P added to the soil. In soil treated with FYM at FYM_3 there were reductions of residual fraction by 22.73 mg kg^{-1} of control treatment. Therefore, the percentage of residual fraction decreased from 16 to 10% of total soil P. Organic matter and soil pH may enhance transformation of some residual P fraction into other P fractions (Fuentes et al., 2008). Reduction of residual P fraction was reported when compost was applied to soil (Lee et al., 2004).

Phosphorus transformations: Distribution of phosphorus (as percentage of total content) among its various fractions in calcareous sandy soil was influenced by FYM additions (Table 2 and Fig. 2). The FYM addition at the highest level increased percentage of some fractions such as NH_4Cl-P, $NaHCO_3$-Pi, $NaHCO_3$-Po and NaOH I-Po from 6.6, 16.4, 12.3 and 4.4 % of total soil P, respectively, at FYM_0 treatment to 8.3, 18.4, 16.8 and 6.9 % of total soil P, respectively. Application of FYM at FYM_1 level caused an increase in the percentage of NaOH I-Pi from 3.9 to 4.5 %, but application of FYM at FYM_2 level resulted in an increase in the percentage of NaOH II-Po from 0.6 to 0.9%. On the other hand, the addition of FYM caused a decrease in HCl-Pi, NaOH II-Pi and residual P fractions from 36.2, 3.8 and 16 % of total soil P at FYM_0, respectively, to 31.9, 0.6 and 10 % of total soil P, respectively at the highest level of FYM (Fig. 2). There were changes in the proportional distribution of P in calcareous sandy soil and P was redistributed among the various fractions during FYM fertilization. The observed decreased amounts of HCl-Pi, NaOH II-Pi and residual P fractions were redistributed on NH_4Cl-P, $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Pi, NaOH I-Po and NaOH II-Po fractions.

Table 2. Mean effects of farmyard manure addition on the amount of available, fractions and total phosphorous in calcareous sandy soil (values are averages of three replications)

		Treatment*			
		FYM_0	FYM_1	FYM_2	FYM_3
Olsen-P (mg kg^{-1})		34.57 C	39.99 B	41.41 B	44.54 A
P fraction (mg kg^{-1})	NH_4Cl-P	29.00 C	37.11 AB	35.91 B	39.81 A
	$NaHCO_3$-P_i	72.14 C	83.43 B	83.31 B	88.42 A
	$NaHCO_3$-P_o	54.16 D	62.81 C	75.10 B	80.33 A
	NaOH I –P_i	17.37 B	20.68 A	18.19 AB	17.37 B
	NaOH I-P_o	19.22 C	27.08 B	29.09 AB	33.28 A
	HCl-P_i	159.50 A	155.61 A	158.39 A	153.16 A
	NaOH II-P_i	16.66 A	15.84 A	16.23 A	16.50 A
	NaOH II-P_o	2.46 B	3.73 A	4.37 A	2.81 B
	Residual P	70.46 A	51.72 B	50.88 B	47.73 B
Total P (mg kg^{-1})		440.97 C	457.99 BC	471.48 AB	479.39 A

The means with the same letter in each row are not significant according to Duncan test at probability of 5%.

* FYM_0 = 0, FYM_1 = 2.5, FYM_2 = 5 and FYM_3 = 7.5 g pot^{-1}

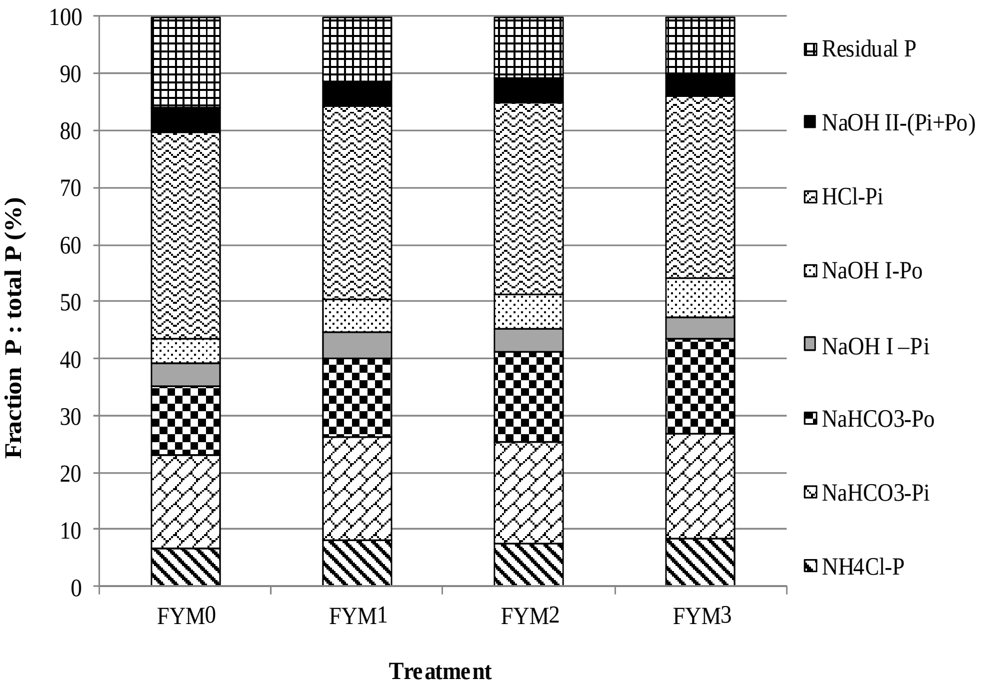

Figure 2. Effect of farmyard manure (FYM) on transformations of phosphorus fractions in calcareous sandy soil as a percentage of total phosphorus

Obviously, when FYM incubated with calcareous sandy soil, some amounts of moderately labile fraction (HCl-Pi) and stable fractions (NaOH II-Pi and residual P) transformed to labile fractions (NH_4Cl-P, $NaHCO_3$-Pi, $NaHCO_3$-Po), some moderately labile fractions (NaOH I-Pi, NaOH I-Po) and some stable fraction (NaOH II-Po). Biosolids application to soil dissolved HCl-P fraction and transformed to $NaHCO_3$-Pi and H_2O-P fractions because soil pH may play role in transformation of HCl-P fraction to other fractions (Sui et al., 1999). Moreover, application of manure to soil caused phosphorus fractions to transform from Al-P and Ca-P into moderately labile Po and moderately resistant Po as well as from O-P to highly resistant Po (Yin and Liang, 2013). Phosphorus fractions of studied calcareous sandy soil influenced by FYM additions which were decreased in the order of HCl-Pi > $NaHCO_3$-Pi >$NaHCO_3$-Po > residual P > NH_4Cl-P > NaOH I-Po > NaOH I-Pi > NaOH II-Pi > NaOH II-Po (Fig. 2). Another study showed that the concentrations of Pi fractions were as follows HCl-Pi > NaOH-P > $NaHCO_3$-P > resin-P in calcareous soils (Yang and Jacobsen, 1990).

Elemental sulfur application

Soil pH and available phosphorus: Adding elemental sulfur to calcareous sandy soil caused significant decrease in soil pH from 7.55 at control treatment (S_0) to 7.36 for the highest level of elemental sulfur (S_3). Applications of elemental sulfur to calcareous sandy soil inoculated with *Thiobacillus* bacteria decreased availability of phosphorus as compared to S_0 treatment (Table 3). Available phosphorus in calcareous sandy soil was decreased from 44.01 mg kg^{-1} at S_0 treatment to 34.63 mg kg^{-1} at the highest level of elemental sulfur. But the addition of S to this soil at S_1 level led to the insignificantly increased of available phosphorus. Elemental sulfur is widely used in most high-pH soils because it reduces soil pH and has a low price. Adding elemental sulfur at highest level to calcareous sandy soil caused a decrease in soil pH. Accordingly, soil pH dropped by 0.19 unit compared to the control after ten weeks of incubation. Soil pH decreases gradually with increasing levels of elemental sulfur added to the calcareous sandy soil. Decline in soil pH due to sulfur oxidation by *Thiobacillus sp*. bacteria produce sulfuric acid. The pH of calcareous sandy soil showed reduction from 8.48 to 7.88 with application of elemental sulfur after 64 days of incubation (Soaud et al., 2011). Oxidization of elemental sulfur in soil by microorganisms and chemical reactions led to a decrease in soil pH because of sulfuric acid production (Tisdale et al., 1997). Applications of elemental sulfur at the highest level to calcareous sandy soil inoculated with *Thiobacillus* bacteria decreased available phosphorus compared to the control. Since the amount of the shortage of available phosphorus was about 9.36 mg kg^{-1} in comparison with the control treatment.

Reduction of the phosphorus availability concentration in this experiment with increasing the elemental sulfur levels except for the S_1 treatment of sulfur as a slight increase in the phosphorus availability. The use of sulfur in the calcareous sandy soil causes a decrease in the availability of phosphorus because of the low pH caused by the addition of sulfur, which leads to the solubility of calcium carbonate thus increasing calcium ions, which react with phosphorus, composed insoluble compounds. In some calcareous soils the available phosphorus decreased from 334.4 to 28.6 mg kg^{-1} at 128 days after incubation by application of P combined with elemental sulfur and sulfur−oxidizing bacteria (Soaud et al., 2011). The addition of sulfur at level 60 kg ha^{-1} led to the decrease of phosphorus availability from 8.12 to 6.82 kg ha^{-1}, while the addition of sulfur at level 20 kg ha^{-1} led to the increase of phosphorus availability from 8.12 to 9.35 kg ha^{-1} compared to the control (Dhage et al., 2014). Elemental sulfur addition to calcareous soil caused a decrease in available Phosphorus due to dissolved calcium carbonate by H_2SO_4 produced from elemental sulfur oxidation resulting in an increase in soluble calcium, which reacts with phosphate forming insoluble calcium phosphate in this soil (Cifuentes and Lindemann, 1993). Availability of phosphorus decreased in soils as level of gypsum application increased because of reaction between soluble Ca^{2+} ions from gypsum and P (Mishra et al., 2003).

Phosphorus fractions

Labile fractions: The obtained results also showed a significant decrease in NH_4Cl-P fraction with applying elemental sulfur compared to S_0 treatment (Table 3). Applications of elemental sulfur to calcareous sandy soil at level S_3 caused a decrease in NH_4Cl-P fraction from 39.52 to 33.86 mg kg^{-1}. Elemental sulfur incubation with the calcareous sandy soil also resulted in non-significant decreases in $NaHCO_3$-Pi fraction up to S_2 level. However, non-significant increase in this fraction occurred by using S_3 level (Table 3). $NaHCO_3$-Pi fraction increased from 81.72 mg kg^{-1} at S_0 treatment to 85.26 mg kg^{-1} at the highest level of elemental sulfur. Non−significant increases were also recorded in $NaHCO_3$-Po fraction at S_1 and S_2 levels as compared to S_0 treatment. However, no significant decrease in the $NaHCO_3$-Po fraction was found at S_3 level. In the present study, elemental sulfur applied as an amendment to the calcareous sandy soil was decreased gradually NH_4Cl-P fraction, where the percentage of this fraction decreased from 8.5 to 7.3% of total soil P. Release of free calcium ions to soil solution due to lowering soil pH and dissolving $CaCO_3$ as result of elemental sulfur additions caused reduction in NH_4Cl-P fraction (Cifuentes and Lindemann, 1993). Previously, concentration of labile P decreased after 2 to13 months of sulfur application (Ye et al., 2010). Elemental sulfur incubation with the calcareous sandy soil also has no much effect on the $NaHCO_3$-Pi and $NaHCO_3$-Po fractions. Values of P fraction associated with Al and Fe decreased steadily after sulfur applications (Ye et al., 2010).

Moderately labile fractions: Adding elemental sulfur to calcareous sandy soil showed insignificant decrease in NaOH I-Pi fraction (Table 3). While, significant increases in NaOH I-Po were found at S_1 and S_2 treatments, but, S_3 treatment did not show significant increases. Applied elemental sulfur to soil at S_1 treatment was found to increase NaOH I-Po fraction from 23.19 to 30.78 mg kg^{-1}. The results illustrated significant decrease in HCl-Pi fraction with application of elemental sulfur. HCl-Pi fraction reduced from 169.86 to 139.94 mg kg^{-1} with elemental sulfur addition at S_3 level to this soil. In the present study, when addition of S to this soil led to increase decrescent of NaOH I-Po fraction. After applying elemental sulfur to soil at S_1 treatment, NaOH I-Po fraction percentage increased from 5.0 to 6.6 % of total P. Ye et al. (2010) found that the amended soil by sulfur did not influence P concentrations in humic-fulvic acid P or alter its proportion to total P. The HCl-P fraction shows a rapid reduction when amended by elemental sulfur, whereas this fraction reduced from 36.7 to 30.3% of total P with elemental sulfur addition at S_3 level. In other words, it was affected by soil amended with elemental sulfur (differences of 29.2 mg kg^{-1}). The HCl-P fraction constituted the largest proportion of the total P in this soil.

Stable fractions: Elemental sulfur at levels of S_1 and S_2 exhibited non−significant changes in NaOH II-Pi fraction of this soil, while applying S_3 level did not increase this fraction (Table 3). Moreover, elemental sulfur additions caused significant increment in NaOH II-Po fraction at S_1 level (Table 3). Elemental sulfur application at S_1 level led to increase in NaOH II-Po fraction from 3.10 to 4.73 mg kg^{-1}. Residual P fraction of this soil showed significant increases due to application of elemental sulfur (Table 3). Elemental sulfur applied at the highest level was found to increase residual P fraction from 42.57 to 74.64 mg. The NaOH II-Po fraction tended to increase in soils with elemental sulfur application at S_1, where the percentage increases from 0.7 to 1.0 % of total P. but the addition of S at levels S_2 and S_3 caused reduced in this fraction. NaOH II-Po fraction is considered the least proportion of total phosphorus in this soil. P concentration in the residual fraction increased after elemental sulfur additions to this soil. Elemental sulfur applied at the highest level was found to increase the proportion of residual P fraction from 9.2 to 16.2 % of total P. However, the residual P was influenced in soils fertilized with elemental sulfur (differences of 32.07 mg P kg^{-1}). However, Ye et al. (2010) reported that sulfur applications to soil did not alter P concentrations of residual fraction or its contribution to the total P.

Phosphorus transformations: Phosphorus distribution as percentage of total content was influenced by elemental sulfur (Fig. 3). Since under incubation treatment S_3 increased $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Po, NaOH II-Pi, NaOH II-Po and residual P fraction from 17.6, 14.6, 5.0, 3.5, 0.7 and 9.2 % of total soil P, respectively, for S_0 to 18.5, 15.5, 6.6, 3.8, 1.0 and 16.2 % of total soil P, respectively. Increases of most previous fractions were slight; except for the residual fraction which was high. Elemental sulfur application to this soil decreased NH_4Cl-P, NaOH I-Pi and HCl-Pi fractions from 8.5, 4.1 and 36.7 % of total soil P, respectively, to 7.3, 3.9 and 30.3 % of total soil P, respectively.

Table 3. Mean effects of elemental sulfur addition on soil pH, the amount of available, fractions and total phosphorous in calcareous sandy soil (values are averages of three replications)

		Treatment*			
		S_0	S_1	S_2	S_3
pH		7.55 A	7.40 B	7.40 B	7.36 C
Olsen-P (mg kg^{-1})		44.01 A	45.56 B	36.31 BC	34.63 C
P fraction (mg kg^{-1})	NH_4Cl-P	39.52 A	35.40 B	33.04 B	33.86 B
	$NaHCO_3$-P_i	81.72 AB	79.39 B	80.93 B	85.26 A
	$NaHCO_3$-P_o	67.63 AB	72.05 A	68.76 AB	63.97 B
	NaOH I –P_i	19.18 A	18.64 A	17.69 A	18.10 A
	NaOH I-P_o	23.19 B	30.78 A	29.04 A	25.66 AB
	HCl-P_i	169.86 A	143.59 B	173.27 A	139.94 B
	NaOH II-P_i	16.36 A	15.97 A	15.40 A	17.50 A
	NaOH II-P_o	3.10 B	4.73 A	2.81 B	2.73 B
	Residual P	42.57 B	65.13 A	38.46 B	74.64 A
Total P (mg kg^{-1})		463.12 AB	465.68 A	459.39 B	461.65 AB

The means with the same letter in each row are not significant according to Duncan test at probability of 5%.
* $S_0 = 0$, $S_1 = 0.1$, $S_2 = 0.2$ and $S_3 = 0.3$ g pot^{-1}

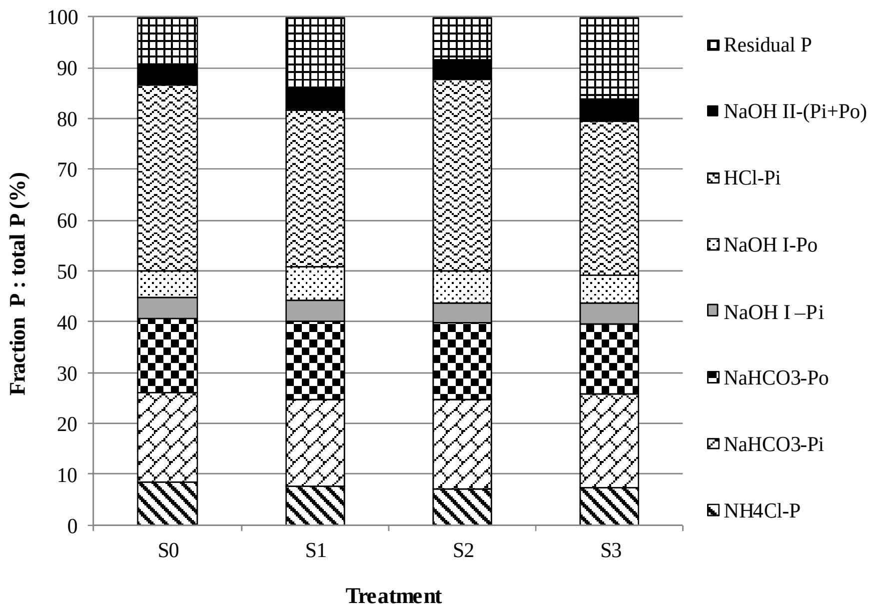

Figure 3. Effect of elemental sulfur (S) on transformations of phosphorus fractions of calcareous sandy soil as a percentage of total phosphorus

Therefore, reduced P amounts of NH_4Cl-P, NaOH I-Pi and HCl-Pi fractions were redistributed and transformed to $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Po, NaOH II-Pi NaOH II-Po and residual P fractions. Phosphorus fractions of calcareous sandy soil decreased in the order of HCl-Pi > $NaHCO_3$-Pi > $NaHCO_3$-Po > residual P > NH_4Cl-P > NaOH I-Po > NaOH I-Pi > NaOH II-Pi > NaOH II-Po as a result of the elemental sulfur application (Fig. 3).

Interaction effects of elemental sulfur and farmyard manure

Soil pH, available and total phosphorus: The combined application of elemental sulfur with farmyard manure decreased soil pH from 7.54 for S_0FYM_0 to 7.35 at highest levels of sulfur and farmyard manure. Also, applications of elemental sulfur with farmyard manure showed significant increases in available Phosphorus of this soil at S_1FYM_1 from 42.95 to 52.70 mg kg^{-1}, while a significant decrease in available soil Phosphorus occurred at S_2FYM_1 (Table 4). Reduced phosphorus availability in calcareous soil might be attributed due to increase calcium ion in soil solution, due to decrease soil pH, that precipitates Phosphorus as octacalcium phosphate. On the other hand, the combined application of elemental sulfur with farmyard manure increased significantly total P of calcareous sandy soil (Table 4). Applying a combination of FYM and elemental sulfur to calcareous sandy soil caused a drop of soil pH compared to the control. Reduction in soil pH was happened by 0.19 unit in comparison with the control treatment. The lowest value of pH in this soil observed at the highest levels of sulfur and farmyard manure. Interaction effect of elemental sulfur and cattle manure applications decreased pH of calcareous soil from 7.79 to 7.44 (Karimi et al. 2012). In the present study, the available phosphorus raised at the additions of mixing FYM and elemental sulfur at level S_1FYM_1 compared to the control. Such treatment has increased about 9.75 mg kg^{-1} compared to the control. The highest values of available phosphorus were observed at S_1FYM_1, S_1FYM_2 and S_1FYM_3. In contrast the lowest concentrations of available phosphorus were observed at S_2FYM_1 and S_3FYM_2. Reduced phosphorus availability in calcareous soil might be attributed to increasing calcium ions in soil solution, due to decreasing soil pH that precipitates phosphorous as octacalcium phosphate.

Phosphorus fractions: Additions of elemental sulfur at S_3 with FYM at FYM_3 level caused a significant increase in the NH_4Cl-P fraction of this soil from 32.89 to 41.16 mg kg^{-1} (Table 4). The combined application of elemental sulfur with farmyard manure at their highest levels also showed significant increase in $NaHCO_3$-Pi fraction of this soil from 61.36 to 91.55 mg kg^{-1}. Moreover, this exhibited a significant increase in $NaHCO_3$-Po fraction. The addition of FYM and S together to this soil raised a $NaHCO_3$-Po fraction from 58.59 mg kg^{-1} to 93.60 mg kg^{-1} at S_1FYM_3. Enhancing the NH_4Cl-P fraction was observed when farmyard manure applied combined with elemental sulfur at S_3FYM_3. The lowest value of the NH_4Cl-P fraction was noticed at S_2FYM_2, where the value of the NH_4Cl-P fraction was 32.61 mg kg^{-1}. The highest value of the NH_4Cl-P fraction was observed at S_3FYM_3. The applied farmyard manure with elemental sulfur increased the percentage of this fraction from 7.3 to 8.3 % at the S_3FYM_3 of the total P, while at S_1FYM_1 the percentage of this fraction increased from 7.3 to 8.8 % of the total P, which represents little changes in the percentage of this fraction. Most treatments combined application of elemental sulfur with farmyard manure led to gradually increase in $NaHCO_3$-Pi and $NaHCO_3$-Po fractions. The percentage of $NaHCO_3$-Pi and $NaHCO_3$-Po fractions increased, however, the highest percentage of $NaHCO_3$-Pi fraction noticed at S_2FYM_2, S_2FYM_3, S_3FYM_1, and S_3FYM_3 treatments. Moreover, the application of S and FMY together to this soil increases the percentage of $NaHCO_3$-Po fraction from 13.1 to 19.4% of total P in soil over incubation period at S_1FYM_3, but the highest values were observed at S_1FYM_3 and S_3FYM_2. However, additions of elemental sulfur with FYM caused insignificant decreases in NaOH I-Pi fraction. On the other hand, additions of S with FYM caused a significant increase in NaOH I-Po fraction of the calcareous sandy soil. Adding S at a level of S_1 with FYM at a level of FYM_3 increased this fraction from 20.82 to 39.92 mg kg^{-1}. Significant reduction in HCl-Pi fraction from 172.00 to 133.65 mg kg^{-1} was found due to application of elemental sulfur with farmyard manure at their highest levels in calcareous sandy soil (Table 4). These were no effects of elemental sulfur with farmyard manure on NaOH II-Pi fraction of this soil (Table 4), while, the interaction effect of S and FYM application was significant for NaOH II-Po fraction. Sulfur treatment at a level of S_1 with FYM at level FYM_1 increased NaOH II-Po fraction from 0.73 to 6.63 mg kg^{-1}. Significant decrease in residual P fraction was observed because of application of elemental sulfur with farmyard manure in this soil (Table 4). Additions of elemental sulfur and FYM caused minor changes of NaOH I-Pi fraction compared to unamended soils. However, the changes of NaOH I-Po fraction were positive significant. The highest concentration of this fraction was founded at S_1FYM_3 accounted about 8.3 % of total P in this soil. In general the concentrations of

HCl-Pi fraction tended to decrease with adding farmyard

Table 4. Interaction effects of elemental sulfur and farmyard manure on the amount of available and fractions of phosphorous of calcareous sandy soil (values are averages of three replications)

Treatment		pH	Olsen-P (mg/kg)	P fraction (mg kg^{-1})									Total P (mg/kg)
S	FYM			NH_4Cl-P	$NaHCO_3$-P_i	$NaHCO_3$-P_o	NaOH I-P_i	NaOH I-P_o	HCl-P_i	NaOH II-P_i	NaOH II-P_o	Residual P	
S_0	FYM_0	7.54 B	42.95 BC	32.89CDEF	61.36 F	58.59 D	19.26 AB	20.82 DEFG	172.00 AB	16.39 ABC	0.73 I	66.59 ABC	448.63 GH
	FYM_1	7.53 B	39.11 CD	38.16 BCD	92.39 A	61.91 CD	22.15 A	16.66 FG	173.95 AB	18.28 AB	3.34 DEFG	23.11 D	449.95FGH
	FYM_2	7.57 A	43.09 BC	41.19 AB	82.01 BCD	74.79 B	17.91 AB	24.05 CDEFG	163.92 B	13.26 BC	4.59 BCD	53.71 C	475.42BC
	FYM_3	7.55 B	50.88 A	45.85 A	91.11 A	75.22 B	17.39 AB	31.23 ABCD	169.57 AB	17.53 ABC	3.73 DEF	26.85 D	478.49BC
S_1	FYM_0	7.45 C	34.49 DE	30.28 EFG	77.71 D	58.59 D	16.03 AB	23.66 CDEFG	134.52 D	15.34 ABC	5.28 ABC	82.19 A	443.61 H
	FYM_1	7.39 EF	52.70 A	40.09 ABC	79.30 CD	63.59 CD	21.00 AB	26.67 BCDEF	144.20 CD	12.62 C	6.63 A	61.82 ABC	455.93EFG
	FYM_2	7.39 E	48.33 AB	34.65BCDE	80.27 CD	72.41 BC	19.79 AB	32.89 ABC	157.34 BC	18.90 A	5.50 AB	59.85 ABC	481.59B
	FYM_3	7.38 EF	46.63 AB	36.60BCDE	80.27 CD	93.60 A	17.74 AB	39.92 A	138.29 D	17.02 ABC	1.49 HI	56.67 BC	481.59B
S_2	FYM_0	7.42 D	36.28 CDE	27.46 FG	68.07 EF	53.48 DE	15.05 B	17.43 EFG	185.57 A	17.79 ABC	1.61 HI	53.58 C	440.04HI
	FYM_1	7.42 D	30.25 EF	36.43BCDE	74.48 DE	70.65 BC	20.53 AB	37.21 AB	164.32 B	14.09 ABC	2.19 FGHI	44.94 CD	464.82DE
	FYM_2	7.37 FG	36.61 CDE	32.61 DEF	90.44 AB	74.39 B	18.61 AB	32.23 ABC	172.06 AB	15.75 ABC	3.50 DEFG	29.74 D	469.33CD
	FYM_3	7.39 EF	42.11 BC	35.65BCDE	90.73 AB	76.52 B	16.55 AB	29.28 ABCD	171.11 AB	13.96 ABC	3.94 CDE	25.58 D	463.32DE
S_3	FYM_0	7.37 FG	24.55 F	25.35 G	81.43 CD	45.98 E	19.12 AB	14.99 G	145.92 CD	17.10 ABC	2.22 FGHI	79.49 AB	431.61I
	FYM_1	7.37 FG	37.91 CD	33.75CDEF	87.53 ABC	55.09 DE	19.03 AB	27.77 BCDEF	139.96 D	18.36 AB	2.76 EFGHI	77.01 AB	461.26DE
	FYM_2	7.35 GH	37.52 CD	35.18BCDE	80.53 CD	78.83 B	16.46 AB	27.19 BCDEF	140.23 D	17.03 ABC	3.87 CDE	60.24 ABC	459.58DEF
	FYM_3	7.35 H	38.55 CD	41.16 AB	91.55 A	75.97 B	17.79 AB	32.67 ABC	133.65 D	17.49 ABC	2.07 GHI	81.81 A	494.16A

The means with the same letter in each column are not significant according to Duncan test at probability of 5%.

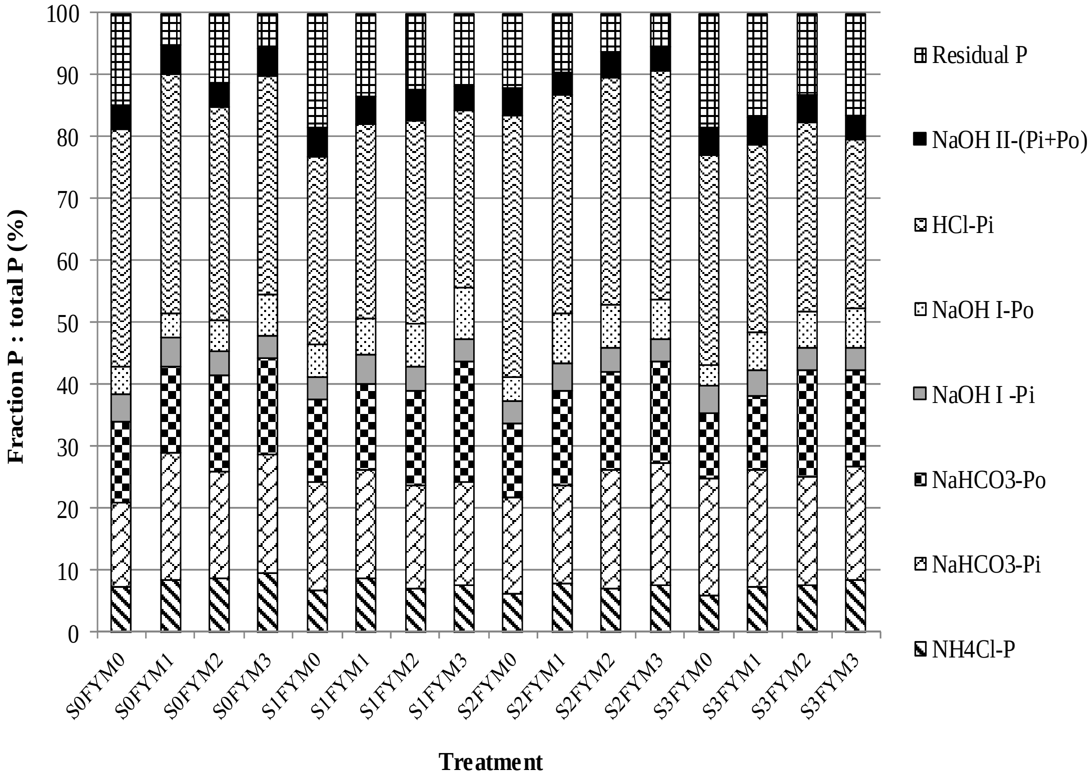

Figure 4. Interaction effects of elemental sulfur and farmyard manure on transformations of phosphorus fractions of calcareous sandy soil as a percentage of total phosphorus

manure and elemental sulfur together to calcareous sandy soil and the proportions of P associated with the HCl-Pi fraction decrease from 38.3 % (S_3FYM_3) to 27.0 % (control) of total P. The concentration of residual P fraction reduced from 66.59 mg kg^{-1} at control to 25.58 mg kg^{-1} for S_2FYM_3. But, at the highest level of sulfur with levels of farmyard manure caused an insignificant increase of residual P fraction, where increased residual P from 66.59 to 81.81 mg kg^{-1}. The NaOH II-Po fraction tended to increase in calcareous sandy soil fertilized via farmyard manure combined with sulfur. Results indicated that, the application of FYM and S together decreases percentage of the residual-P fraction from 14.8 to 5.5 % of total P at S_2FYM_3 treatment compared to the control. In contrast the additions of FYM with S at highest levels caused the increase of residual-P fraction. The highest value of residual-P fraction was observed at S_3FYM_3, while the lowest value of this fraction noticed at S_2FYM_3.

Phosphorus transformations: Additions of elemental sulfur, at high level and farmyard manure at the highest level, to calcareous sandy soil increased NH_4Cl-P, $NaHCO_3$-Pi, $NaHCO_3$-Po, NaOH I-Po, NaOH II-Po and residual fractions from 7.3, 13.7, 13.1, 4.6, 0.2 and 14.6 % of total soil P, respectively, to 8.3, 18.5, 15.4, 6.6, 0.4 and 16.6 % of total soil P, respectively, on the expense of decreasing NaOH I-Pi, HCl-Pi and NaOH II-Pi fractions from 4.3, 38.3 and 3.7 % of total soil P, respectively, to 3.6, 27.0 and 3.5 % of total soil P, respectively (Fig. 4). Therefore, decrease in P of NaOH I-Pi, HCl-Pi and NaOH II-Pi fractions were redistributed and transformed to NH4Cl-P, NaHCO3-Pi, NaHCO3-Po, NaOH I-Po, NaOH II-Po and residual fractions due to addition of elemental sulfur with farmyard manure.

CONCLUSION

Converting the phosphate ions produced from phosphate fertilizers to insoluble phosphate reduces the availability of soil phosphorus. Adding farmyard manure with elemental sulfur is considered to be important help in the progress of phosphorus availability in calcareous sandy soil, which is one of management and reclamation methods of this soil. This in turn leads to improve production efficiency of the soil. Since the applications of farmyard manure to the sandy calcareous soil converts the non labile fractions to labile and moderately labile fractions, we can recommend that adding farmyard manure to calcareous sandy soil as well as adding elemental sulfur at low levels combined with FYM.

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الملخص العربي

صلاحية وتحولات الفوسفور في التربة الجيرية الرملية المتأثرة بإضافة السماد البلدى و الكبريت العنصري

ابو العيون ابو زيد امين

أجريت تجربة تحضين لدراسة تـأثير السماد البلدى والكبريت العنصرى على توافر، صور وتحويل الفوسفور في التربة الجيرية الرملية. تمت معالجة عينات التربة باستخدام السماد البلدى بمستويات: صفر، ٢,٥ ، ٥ و ٧,٥ جم/الاصيص و الكبريت عند مستويات: صفر، ٠,١ ، ٠,٢ و ٠,٣ جم / الاصيص. تم تحضين التربة لمدة عشرة أسابيع تحت ظروف السعة الحقلية. تسببت إضافات السماد البلدى في حدوث زيادات معنوية في كمية الفوسفور الميسر من ٣٤,٥٧ إلى ٤٤,٥٤ مجم/كجم. وقد أدى تطبيق الكبريت مع السماد البلدى إلى زيادة معنوية في كمية الفوسفور الميسر لهذه التربة عند المستوى الاول من السماد البلدى والكبريت من ٤٢,٩٥ إلى ٥٢,٧٠ مجم/كجم. لوحظ انخفاض معنوي في كمية الفوسفور الميسر عند مستوي الكبريت الثانى و الثالث ، ولكن إضافة الكبريت عند المستوى الاول أدى إلى زيادة غير معنوية. إضافة السماد البلدى أدت الى تحول صور الفوسفور المستخلص بحامض الهيدروكلوريك و الفوسفور المعدنى المستخلص بواسطة هيدروكسيد الصوديوم ٢ و الفوسفور المتبقي إلى صور الفوسفور المستخلص بواسطة كلوريد الامونيوم و الفوسفور المعدنى المستخلص بواسطة بيكربونات الصوديوم و الفوسفور العضوى المستخلص بواسطة بيكربونات الصوديوم و الفوسفور المعدنى المستخلص بواسطة هيدروكسيد الصوديوم ١ و الفوسفور العضوى المستخلص بواسطة هيدروكسيد الصوديوم ١ والفوسفور العضوى المستخلص بواسطة هيدروكسيد الصوديوم ٢. إضافة الكبريت أدت الى تحول صور الفوسفور المستخلص بواسطة كلوريد الامونيوم ، الفوسفور المعدنى المستخلص بواسطة هيدروكسيد الصوديوم ١و الفوسفور المستخلص بحامض الهيدروكلوريك إلى صور الفوسفور المعدنى المستخلص بواسطة بيكربونات الصوديوم، الفوسفور العضوى المستخلص بواسطة بيكربونات الصوديوم، الفوسفور العضوى المستخلص بواسطة هيدروكسيد الصوديوم ١، الفوسفور المعدنى المستخلص بواسطة هيدروكسيد الصوديوم ٢ ، والفوسفور العضوى المستخلص بواسطة هيدروكسيد الصوديوم ٢ والفوسفور المتبقى. نوصى بإضافة السماد البلدى إلى التربة الجيرية الرملية وكذلك إضافة الكبريت مع السماد البلدى لتحسين خصائص التربة.