



## INTEGRATED METHODS FOR INCREASING P-SOLUBILITY OF PHOSPHATE ROCK

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### ABSTRACT

Laboratory experiments were carried out to study the effect of some integrated factors on solubility of phosphate rock (PR) obtained from two locations which were Abou Tartour and El-Sibaia Gharb as well as tricalcium phosphate. PRs were crushed to pass through a 1.18-mm sieve and separated into 7 particle diameters of 500, 250, 212, 125, 75 and 45  $\mu\text{m}$ . Scanning Electron Microscope "SEM" and X-ray diffraction were done. P-solubility was assessed using water and 5 acids of formic (FR), Acetic (AC), tartaric (TR) oxalic (OX) and citric (CT) (each of 2%). P in Abou Tartour samples was mainly as calcium phosphate hydroxide " $\text{Ca}_5(\text{PO}_4)_6 \text{OH}$ ". Other crystalline were silicon oxide  $\text{SiO}_2$ , calcium carbonate  $\text{CaCO}_3$  and calcium di-hydrogen phosphate hydrate  $\text{Ca H}_2\text{PO}_4$ . P in El-Sibaia samples was mainly in form of Brushite. P contents ( $\text{g kg}^{-1}$ ) were 0.2 to 0.6 water-soluble, and 10 – 17 for Olsen extract. Ranges for the acid-extractants from the two PRs were 39-44 for CT, 25-41 for AC, 27-49 for TR, 14-28 for OX and 32-52 for FA. A tendency to increase with decreased particle size occurred. Practical aspects could be inferred regarding the use of PR for fertilization.

**Key words:** Phosphate rock, P solubility, x-ray of P-rocks, scanning electron microscopy.

### INTRODUCTION

Phosphorus (P) is an essential nutrient element which has several functions in plants and animals growth. The appropriate and sound utilization of phosphate rocks (PRs) as P sources can contribute to sustainable agriculture intensification, particularly in developing countries endowed with PR resources. PR is the primary raw material for manufacturing P fertilizers. Therefore there are various methods for evaluating PRs for direct application.

Direct application of PRs enables utilization of PR sources that cannot be utilized for industrial purposes in the manufacture of water soluble fertilizers. Direct application of PRs in sustainable agriculture can be more efficient than water soluble P- fertilizers in terms of P recovery by plants. Based on the unit cost of P, natural or indigenous PRs is usually the cheapest. Because of their extremely variable and complex chemical composition, PRs are

sources of several nutrients other than P. They are usually applied to replenish soil P, and upon dissolution they provide other nutrients contained in them.

Characterization studies on PRs should provide data on (i) the composition of the apatite and other phosphate minerals; (ii) relative contents of mineral species and (iii) particle size distribution of the pulverized rock. Egypt produces 0.7% of world phosphate rock production (Mew, 2000). Local phosphate rock resources includes Abou-Tartour and El Sibaia Gharb locations.

Root exudates in the rhizosphere include organic acids such as oxalic, citric, formic, malic, acetic, tartaric, which decrease soil pH, act as chelating compounds and increase P solubility (Dinkelaker *et al.*, 1989; Hoffland *et al.*, 1992; Al-Oud, 2011; Marschner, 2012).

The current study involves characterization of Abou Tartour and El Sibaia Gharb PR,

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through using various techniques including solubility in water and some organic acids, Scanning Electronic Microscope (SEM) with EDX unit, X-ray diffraction, and particle-size distribution.

## MATERIALS AND METHODS

Laboratory experiments were carried out to study the effect of some integrated factors on solubility of PR-P in two PR sources (from Abou-Tartour and El-Sibaia Gharb) as well as tricalcium phosphate.

### Preparation of Materials

Phosphate rocks were crushed to pass through a 1.18-mm sieve. One kg of each source was sieved to pass a set of sieves with the following diameters 500, 250, 212, 125, 75 and 45  $\mu\text{m}$  (using Electric Sieve Shaker). Part of the PR from the <45- $\mu\text{m}$  fraction was further ground manually for comparison with the other parts. The weights of each diameter of the samples were recorded and are shown in Table 1.

### Identification and Classification

Identification and classification of the pulverized rock phosphate were done through scanning with electronic microscope (Plate 1) and x ray diffraction for the two PR sources. Solubility tests were done on the two PRs and the tricalcium phosphate.

#### Solubility and extractability tests

Determinations of water-soluble P, Na-bicarbonate-soluble P (available Olsen extract), citric acid-soluble P and total P were done.

#### Experiments

Two experiments were done to assess some factors on PR solubility.

##### Experiment 1 (Particle size and P solubility)

To study the effect of particle size on PR solubility. Samples of different particles size were analyzed for water soluble, Na-bicarbonate extractable and citric acid extractable P. Samples (0.5-g each) of the different size fractions of

:500, 250, 212, 125, 75, 45 and < 45  $\mu\text{m}$  were extracted ; each with 100-ml acid solution .Total P was also assessed.

##### Experiment 2 (Comparative P-solubility by organic acids)

To study the comparative PR solubility using 5 acid extractants :formic acid 2%, Acetic acid 2%, tartaric acid 2%, oxalic acid 2% and citric acid 2%. Such organic acids are exudated by plant roots in the rhizosphere.

##### P-extraction and analysis

Extractable P was extracted on each of the different particle fractions of 500, 250, 212, 125, 75, 45 and < 45  $\mu\text{m}$   $\emptyset$  > Total P was also analyzed. Weight of extracted samples for each fraction was in 5 categories : 0.10, 0.20, 0.30, 0.40 and 0.5g. Each was extracted by 100 ml of extractant. As for total P, samples representing the different size fractions as well as the hand-ground were digested by concentrated acid mixture of  $\text{H}_2\text{SO}_4/\text{HClO}_4$ .

##### Water-Soluble P

Extraction was by distilled water, shaking for one hour then filtration through Whatman 42 filter paper (Chapman and Pratt, 1961).

##### Na-bicarbonate-soluble P (Olsen extract)

Extraction was by 0.5 M  $\text{NaHCO}_3$  solution at pH8.5 after shaking for half an hour (Olsen *et al.*, 1954).

##### Citric acid-soluble P

Extraction was by 2% citric acid; then shaking was done for 30 min followed by filtration through Whatman 42 filter paper and P was measured in the filtrates.

##### Total P

0.5-g was digested by 10 ml concentrated  $\text{H}_2\text{SO}_4$  + 5 ml  $\text{HClO}_4$  on a heater. After the mixture was clear, the digest was transferred to a 100-ml measuring flask and the volume were made up with distilled water (Jackson, 1958).

Phosphorus was determined in the extracts or digests using a colorimetric method of the ascorbic acid method (Murphy and Riley, 1977).

**Table 1. Weight (g) of different fractions after sieving**

Sieve		Source		
$\mu\text{m}$	Mesh	Abou Tartour	El-Sibaia	Tricalcium phosphate
>1180	16	66.73	118.79	0.00
<1180 - >500	35	260.42	497.42	10.00
500 - >250	60	204.05	160.74	98.40
250 - >212	70	122.70	48.86	141.00
212 - >125	120	132.04	57.12	250.10
125 - >75	200	75.10	47.88	320.00
75 - >45	325	105.57	45.93	130.00
< 45	>325	33.74	23.26	50.50

## RESULTS AND DISCUSSION

### Classification and Identification of P in the PR Sources

#### The X-ray diffraction analysis

The X-ray diffraction was carried out by scanning a powdered sample of each PR sources (Fig. 1). The diffraction pattern revealed that P in Abou Tartour PR exists in the form of calcium phosphate hydroxide  $\text{Ca}_5(\text{PO}_4)_6 \text{OH}$ . The other crystalline phase was in the form of silicon oxide  $\text{SiO}_2$ , calcium carbonate  $\text{CaCO}_3$  and calcium di-hydrogen phosphate hydrate  $\text{CaH}_2\text{PO}_4$ . Phosphorus in El-Sibaia Gharb phosphate rock sample exists in the form of Brushite  $\text{CaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ . The other crystalline phase was sodium calcium aluminum "Albite"  $\text{Na}_{0.499} \text{Ca}_{0.491} (\text{Al}_{1.488} \text{Si}_{2.5} \text{O}_8)$  and "Ferroan" calcium iron magnesium silicon oxide;  $\text{Ca Mg}_{0.82} \text{Fe}_{0.18} \text{Si}_2 \text{O}_6$ .

#### Scanning electron microscope "SEM"

Plate 2 shows that the apatite grain size ranged between 4.941  $\mu\text{m}$  to 25.76 nm in the hand ground sample of Abou Tartour. On the other hand the apatite grains size of El-Sibaia Gharb PR ranged between 28.37  $\mu\text{m}$  to 7.310  $\mu\text{m}$  in the <45  $\mu\text{m}$ .

#### Total P in different size fractions

Total P in Abou Tartour PR ranged from 130.6 to 133.0  $\text{g kg}^{-1}$  and value for the ground\* PR was 139.4. Total P in El-Sibaia PR ranged

from 72.4 to 78.6  $\text{g kg}^{-1}$ , and value for the ground\* PR was 88.8. Total P for tricalcium phosphate ranged from 166.8 to 182.5. For all three sources, there was a trend of increasing total P with decreasing size of particles. The hand-ground particles showed P higher than any of the size fractions (Table 2).

#### Ranking of phosphate rock sources

According to the ranking of Diamond (1979), the Abou-Tartour PR is of a high grade whereas the PR of El-Sibaia is of a medium grade. The high grade is considered most appropriate for sustainable agriculture (Table 3).

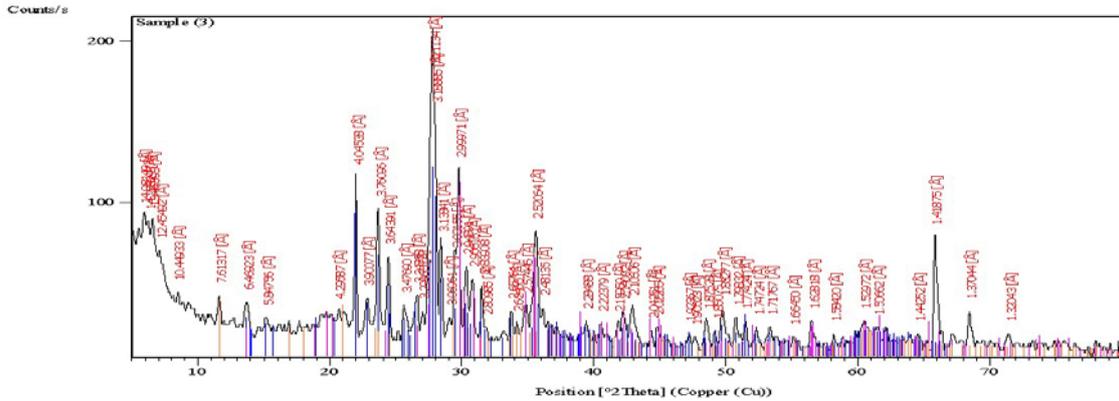
#### Forms of P in PR and tricalcium phosphate sources

##### Water-soluble P

Water soluble P contents were very low, not exceeding 1 and ranged from about 0.2 to 0.6  $\text{g kg}^{-1}$ . Values ( $\text{g P kg}^{-1}$ ) in Abu Tartour PR (Fig. 2) ranged from 0.246 to 0.300 for the 0.1-g sample, 0.255 to 0.357 for the 0.2-g sample, 0.279 to 0.397 for the 0.3-g sample, 0.282 to 0.415 for the 0.4-g sample and 0.282 to 0.412 for the 0.5-g sample. For the El-Sibaia (Fig. 3) ranges were as follows: 0.246 to 0.300, 0.270 to 0.403, 0.288 to 0.415, 0.297 to 0.427 and 0.303 to 0.451 for the aforementioned weight categories respectively. For the tricalcium phosphate (Fig. 4) ranges were as follows: 0.282 to 0.421, 0.282 to 0.454, 0.282 to 0.493, 0.291 to 0.517 and 0.303 to 0.553 for the aforementioned weight categories, respectively (Tables 4 and 5).

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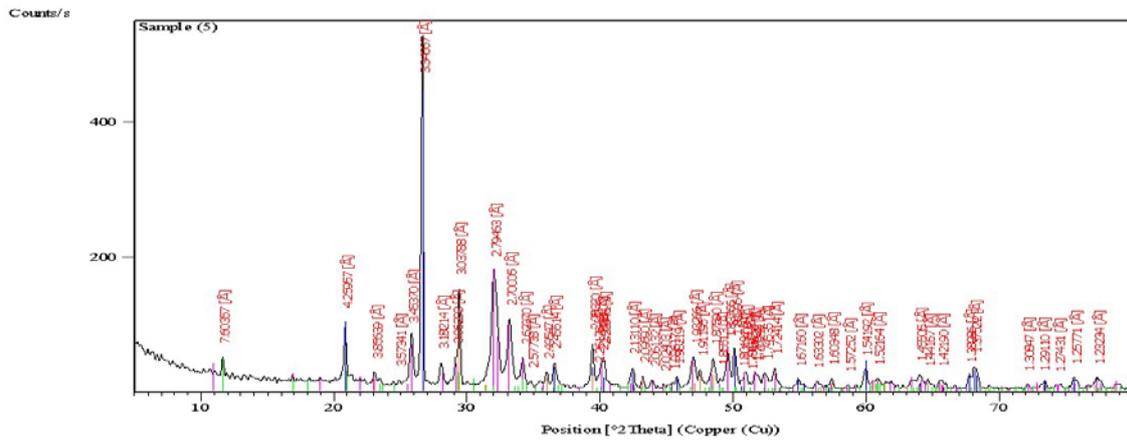
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Fig. 1. X-ray diffraction for Abu Tartour PR and El-Sibaia Gharb PR



Plate 1. SEM with EDX unite

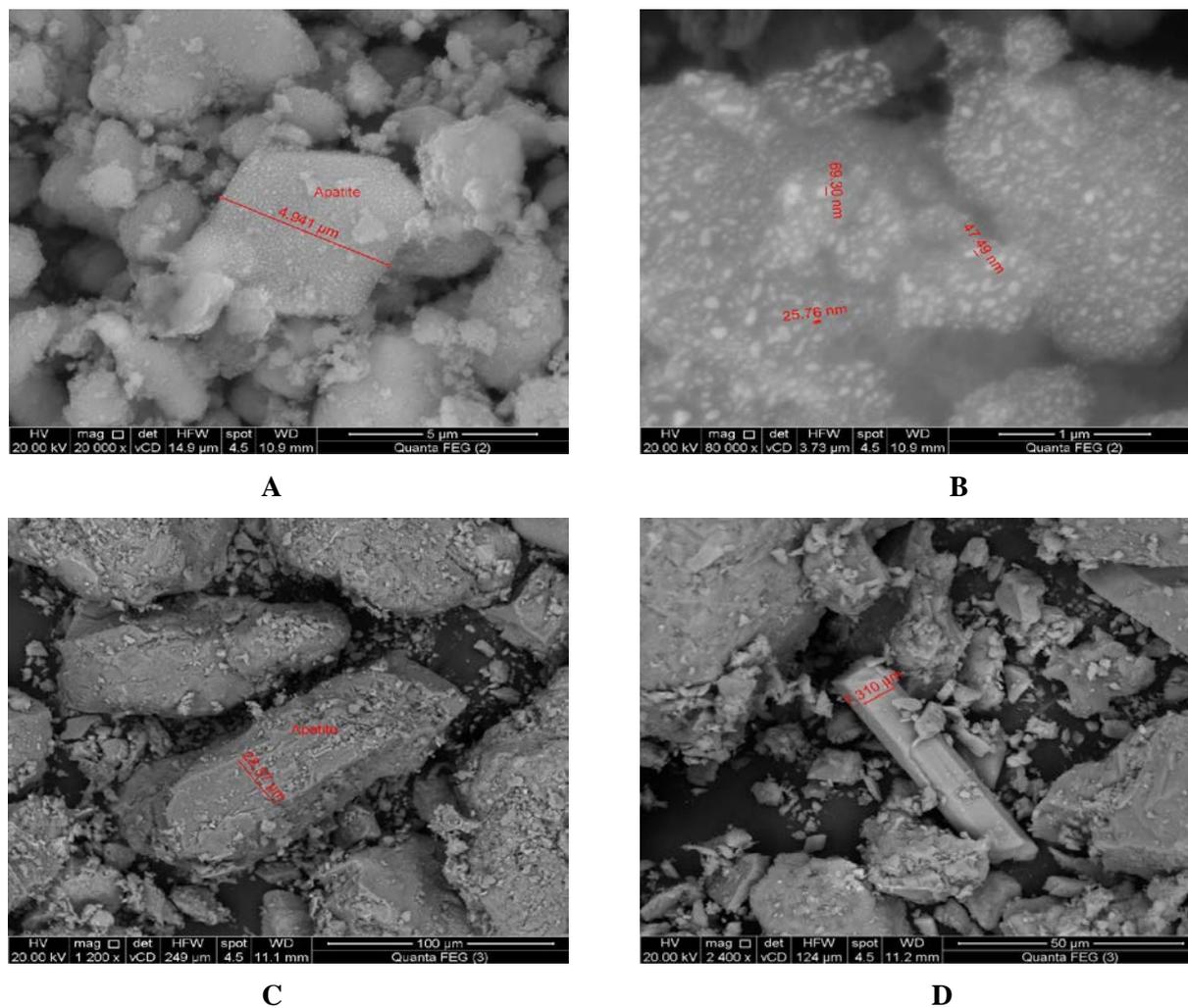


Plate 2. PR SEM of Abou Tartour PR (A and B) and (C and D) El-Sibaia Gharb PR

Table 2. Total P ( $\text{g kg}^{-1}$ ) content in different PRs A- Abou Tartour, B-El-Sibaia Gharb, C-Tri Calcium Phosphate as affected by particles size (weight of analyzed sample = 0.5 g)

Sources	Diameter ( $\mu\text{m}$ )							Ground*	Mean
	500	250	212	125	75	45	<45		
Total P ( $\text{g kg}^{-1}$ )									
A	130.6	131.5	131.9	132.0	132.2	132.6	133.0	139.4	132.90
B	72.4	74.2	74.3	74.8	75.3	76.7	78.6	88.8	76.89
C	190.0	191.2	194.1	194.8	195.0	196.0	196.7	nd*	194.0

nd: Grinding of Tri-calcium phosphate was not done. Ground\*:  $<<45 \mu\text{m}$  : 25 nm

**Table 3. Total and extractable P (g kg<sup>-1</sup>) content in different PRs A- Abou Tartour, B-El-Sibaia Gharb, C-Tri Calcium Phosphate and ranking grades (according to Diamond 1979) for sustainable agriculture**

Source	P content of various forms (g kg <sup>-1</sup> )				Ranking
	Total	Water-soluble	Available*	Citric acid soluble	
A- Abou Tartour	130.6	0.28	14.15	40.22	High
B- El-Sibaia Gharb	72.40	0.30	14.39	32.51	Medium
C- Tri Calcium phosphate	190.0	0.30	15.97	78.62	High

\* Na-bicarbonate extract

**Table 4. Water soluble P “Olsen extract” (g kg<sup>-1</sup>) in different particle-size fractions of PR sources and tricalcium phosphate using different sample weights (extractant per sample=100ml)**

Weight of sample(g)	Diameter(μm)							Mean
	500	250	212	125	75	45	<45	
<b>A- Abou Tartour</b>								
<b>0.1</b>	0.246	0.258	0.282	0.285	0.285	0.297	0.300	0.279
<b>0.2</b>	0.255	0.282	0.318	0.342	0.351	0.354	0.357	0.323
<b>0.3</b>	0.279	0.303	0.324	0.342	0.357	0.384	0.397	0.341
<b>0.4</b>	0.282	0.327	0.345	0.354	0.378	0.391	0.415	0.356
<b>0.5</b>	0.282	0.294	0.315	0.327	0.345	0.387	0.412	0.338
<b>Mean</b>	0.269	0.293	0.317	0.330	0.344	0.363	0.376	0.327
<b>B- El-Sibaia Gharb</b>								
<b>0.1</b>	0.246	0.255	0.270	0.288	0.288	0.297	0.300	0.278
<b>0.2</b>	0.270	0.285	0.300	0.342	0.357	0.384	0.403	0.335
<b>0.3</b>	0.288	0.291	0.327	0.345	0.378	0.406	0.415	0.350
<b>0.4</b>	0.297	0.312	0.330	0.348	0.360	0.394	0.427	0.353
<b>0.5</b>	0.303	0.315	0.336	0.351	0.391	0.406	0.451	0.365
<b>Mean</b>	0.281	0.292	0.313	0.335	0.355	0.377	0.399	0.336
<b>C- Tri Calcium Phosphate</b>								
<b>0.1</b>	0.282	0.288	0.306	0.342	0.378	0.397	0.421	0.345
<b>0.2</b>	0.282	0.291	0.324	0.366	0.394	0.427	0.454	0.363
<b>0.3</b>	0.282	0.303	0.336	0.397	0.454	0.481	0.493	0.392
<b>0.4</b>	0.291	0.339	0.369	0.430	0.460	0.484	0.517	0.413
<b>0.5</b>	0.303	0.366	0.394	0.451	0.484	0.508	0.553	0.437
<b>Mean</b>	0.288	0.318	0.0346	0.397	0.434	0.459	0.487	0.390

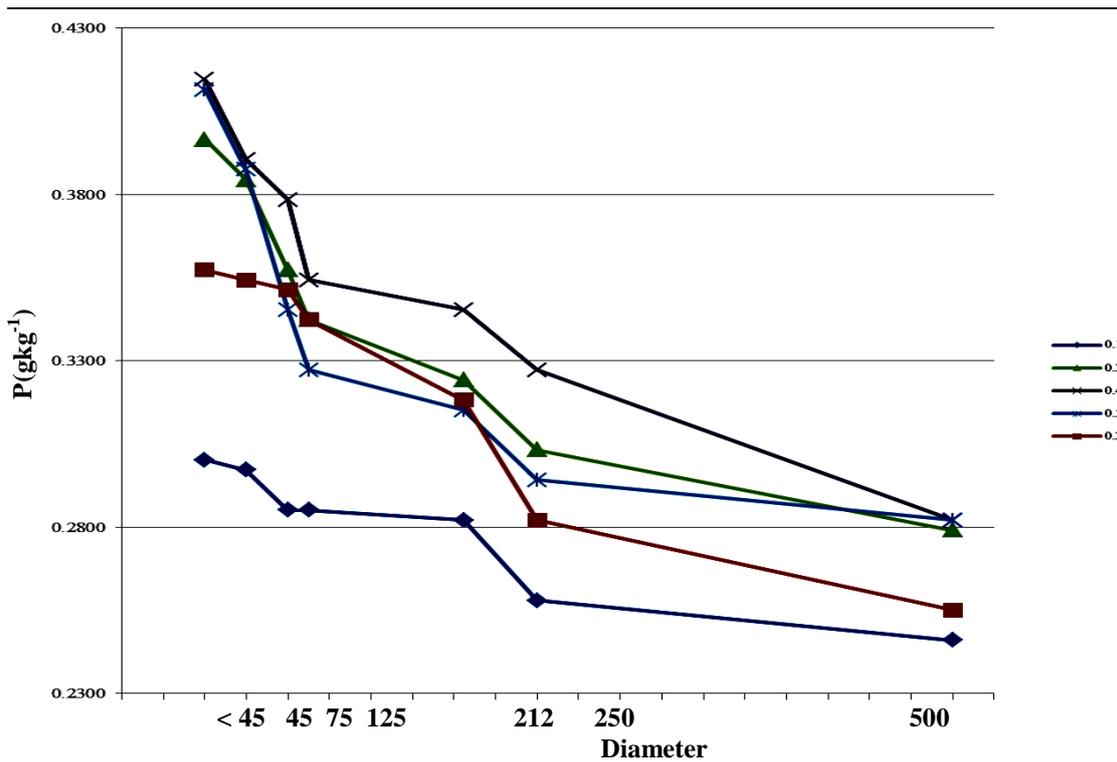


Fig. 2. Water-soluble P (gkg<sup>-1</sup>) of different phosphate rocks particles A- Abou Tartour

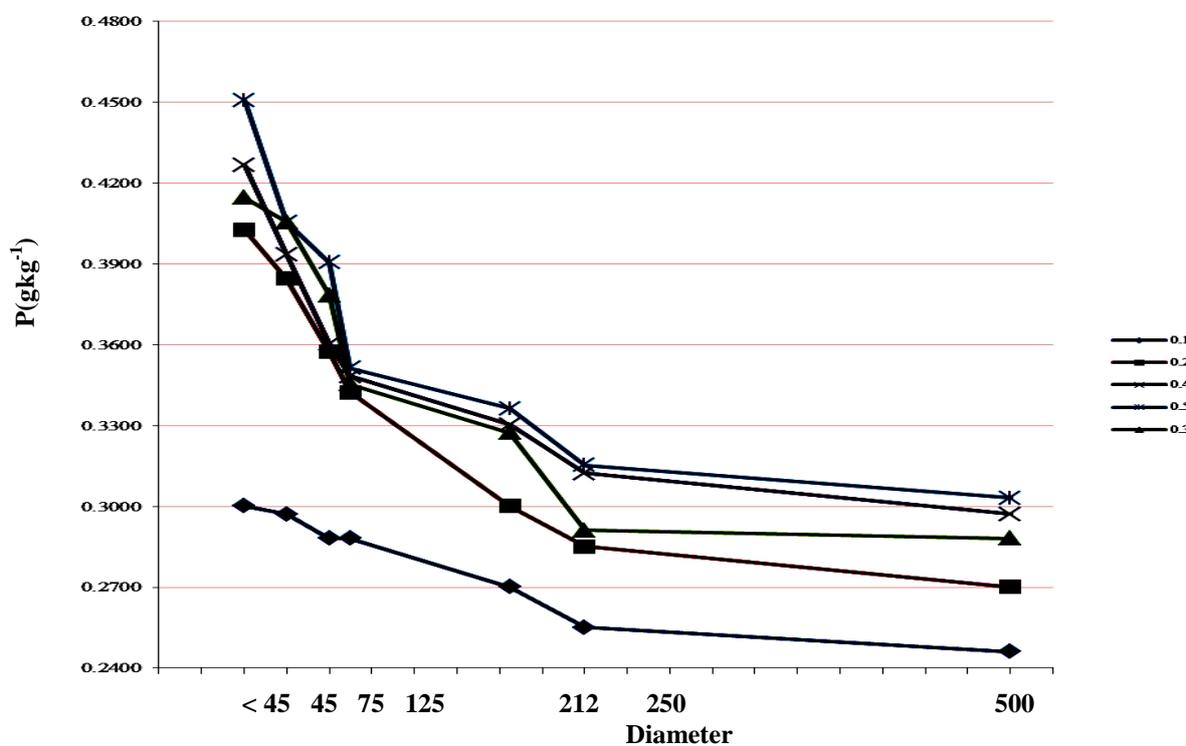
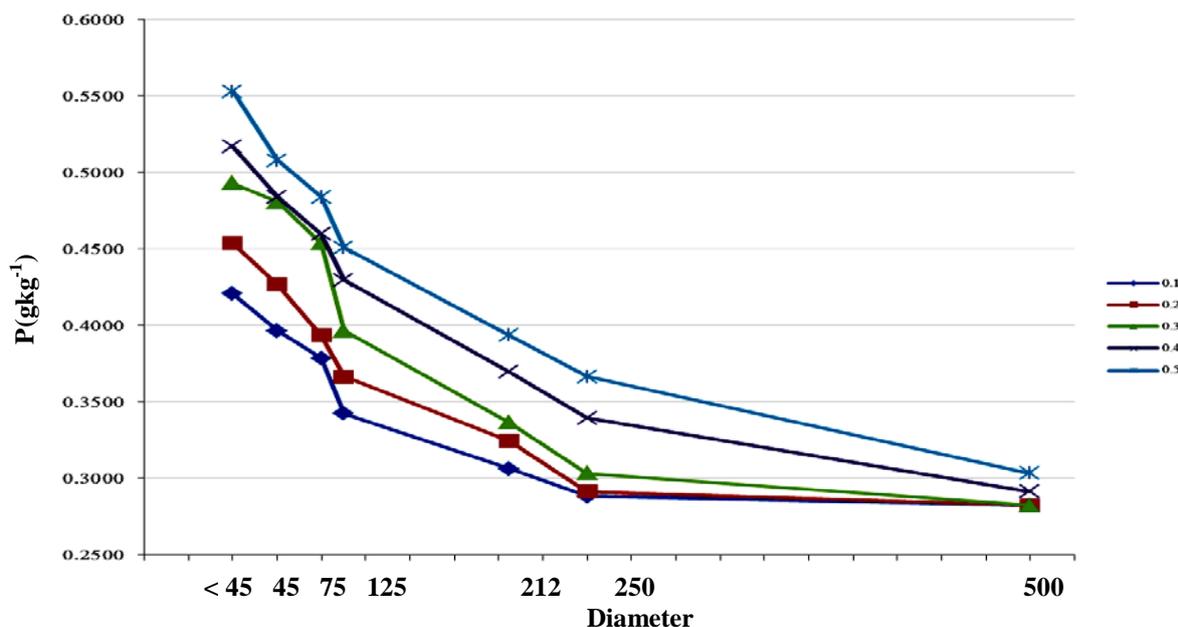


Fig. 3. Water-soluble P (gkg<sup>-1</sup>) of different phosphate rocks particles B- El-Sibaia Gharb



**Fig. 4. Water-soluble P (gkg<sup>-1</sup>) of different phosphate rocks particles C- Tri calcium phosphate (each sample was extracted by 100-ml extractant)**

In all of the three sources, there was a trend of increase with decreasing size of particles. Also a trend of increased content occurred with the increase in the sample weight.

#### (Available P) Olsen extract

Extraction with sodium bicarbonate showed greater values than given by the water soluble extracts ranging from about 10 to 17 g kg<sup>-1</sup>. Values in Abu-Tartour PR (Fig. 5) ranged from 09.87 to 11.14, 10.27 to 10.97, 10.27 to 13.22, 10.24 to 12.31 and 14.15 to 14.54 g P kg<sup>-1</sup> for the sample weight fractions of 0.1, 0.2, 0.3, 0.4 and 0.5-g, respectively. El-Sibaia PR (Fig. 6) showed ranges as follows: 9.94 to 10.54, 9.94 to 12.51, 10.00 to 12.51, 10.30 to 12.98 and 14.40 to 16.05 g P kg<sup>-1</sup> for same above-mentioned sample weight fractions. Values for the tricalcium phosphate (Fig. 7) were in the range of 15.53 to 16.35, 15.60 to 16.89, 15.73 to 17.30, 15.78 to 17.45 and 15.98 to 17.48 g P kg<sup>-1</sup> for same above-mentioned sample weight fractions.

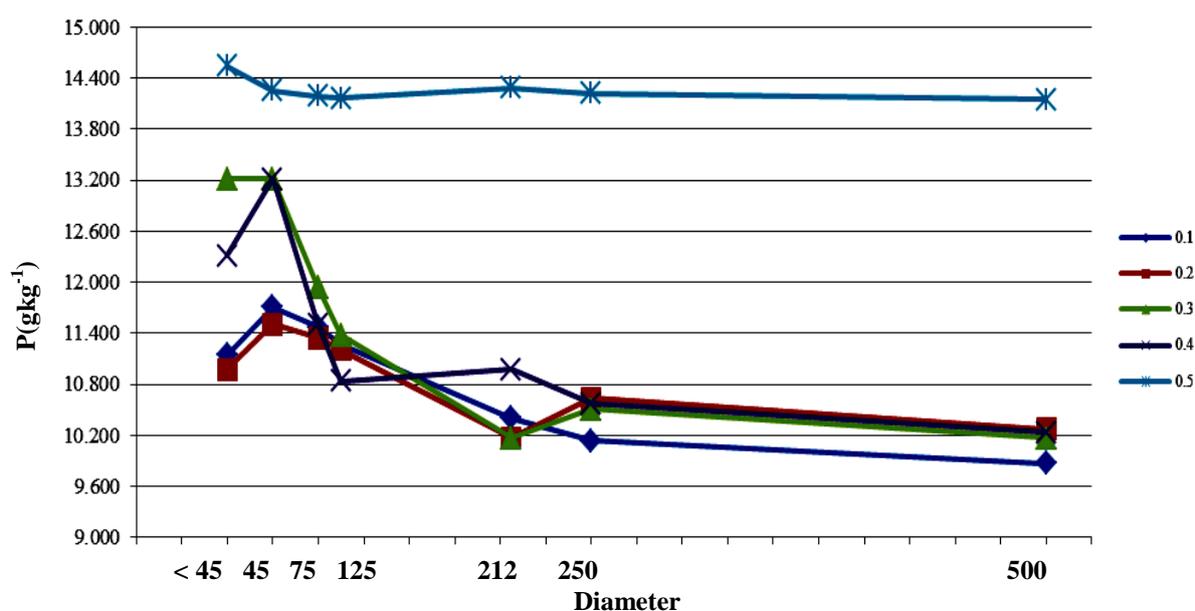
#### Citric acid extractable P

Phosphorus extracted by citric acid was greater than extracted by water or by Na-

bicarbonate. The values ranged from about 36 to 85 g kg<sup>-1</sup> as an acid, such acidic extractant would extract greater amounts of P from the insoluble sources of PR or the tricalcium phosphate (Mostara and Datta, 1971). Values in Abu-Tartour PR (Fig. 8) ranged from 36.37 to 47.04, 37.55 to 48.38, 38.30 to 50.16, 38.89 to 52.08 and 40.22 to 52.53 g P kg<sup>-1</sup> for the sample weight fractions of 0.1, 0.2, 0.3, 0.4 and 0.5-g, respectively. El-Sibaia PR (Fig. 9) showed ranges of 27.03 to 34.59, 27.47 to 36.66, 30.88 to 38.59, 31.62 to 40.37 and 32.51 to 41.56 g P kg<sup>-1</sup> for the above-mentioned sample weight fractions, respectively. Values for the tricalcium phosphate (Fig. 10) were in the range of 74.92 to 80.99, 75.81 to 82.92, 75.81 to 83.98, 76.55 to 83.96 and 78.62 to 84.55 g P kg<sup>-1</sup> for the above-mentioned sample weight fractions, respectively. The trend of increase with decreased size of particles, and the trend of increased content occurred with the increase in the sample weight observed for the other extractants of water and Na\bicarbonate were also observed with the citric acid extractant.

**Table 5. Na-bicarbonate-soluble P “Olsen extract” ( $\text{g kg}^{-1}$ ) in different particle-size fractions of PR sources and tricalcium phosphate using different sample weights (extractant per sample=100 ml)**

Weight of sample(g)	Diameter ( $\mu\text{m}$ )							Mean
	500	250	212	125	75	45	<45	
<b>A- Abou Tartour</b>								
0.1	9.87	10.14	10.41	11.28	11.48	11.71	11.14	10.86
0.2	10.27	10.64	10.17	11.21	11.34	11.51	10.97	10.87
0.3	10.17	10.51	10.17	11.38	11.94	13.22	13.22	11.51
0.4	10.24	10.57	10.97	10.84	11.51	13.22	12.31	11.38
0.5	14.15	14.22	14.28	14.17	14.18	14.25	14.54	14.25
Mean	10.94	11.21	11.20	11.77	12.09	12.78	12.44	11.78
<b>B- El-Sibaia Gharb</b>								
0.1	09.94	10.07	10.17	10.24	10.51	10.67	10.54	10.30
0.2	09.94	10.17	11.07	12.35	12.55	12.68	12.65	11.63
0.3	10.00	10.64	10.97	11.98	12.58	12.71	12.51	11.63
0.4	10.30	10.81	11.34	12.61	13.01	13.32	12.98	12.05
0.5	14.40	14.64	15.51	15.23	15.76	15.93	16.05	15.36
Mean	10.92	11.27	11.81	12.48	12.88	13.06	12.95	12.20
<b>C- Tri Calcium Phosphate</b>								
0.1	15.53	15.59	15.98	16.04	16.16	16.29	16.35	15.99
0.2	15.60	15.75	16.11	16.21	16.66	16.75	16.89	16.28
0.3	15.73	15.79	16.66	16.93	17.11	17.20	17.30	16.68
0.4	15.78	15.93	16.76	17.11	17.21	17.30	17.45	16.79
0.5	15.98	16.18	16.50	16.59	16.77	17.29	17.48	16.68
Mean	15.72	15.85	16.40	16.58	16.78	16.97	17.10	16.49



**Fig. 5. Available P ( $\text{gkg}^{-1}$ ) of different phosphate rocks particles A- Abou Tartour**

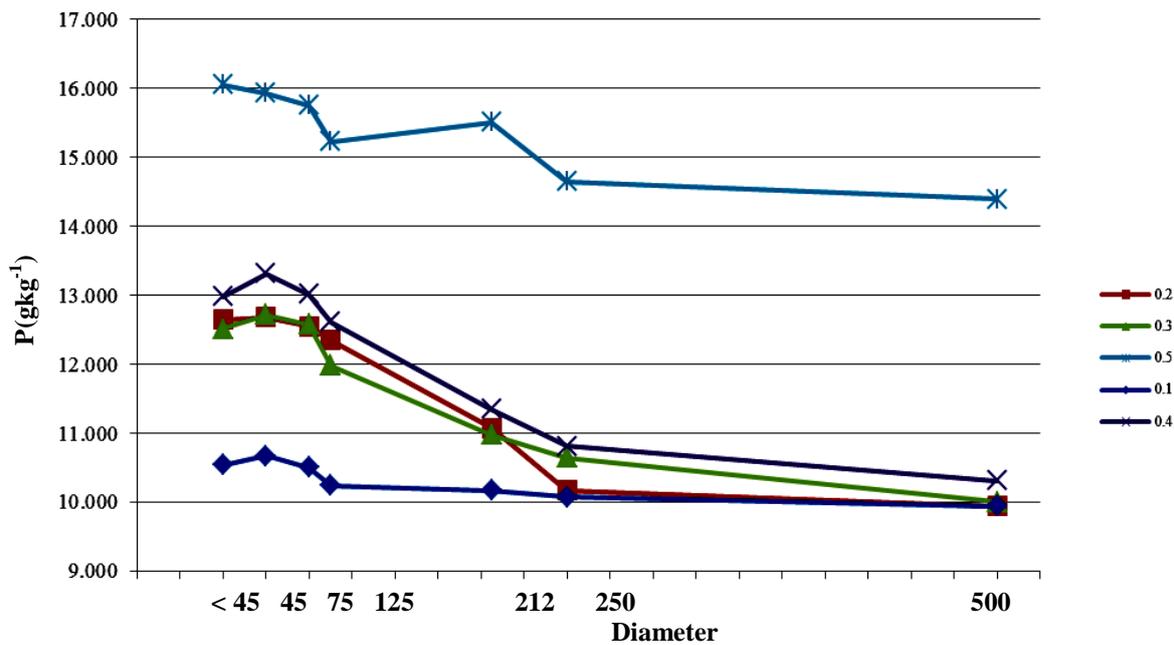


Fig. 6. Available P (gkg<sup>-1</sup>) of different phosphate rocks particles B- El-Sibaia Gharb

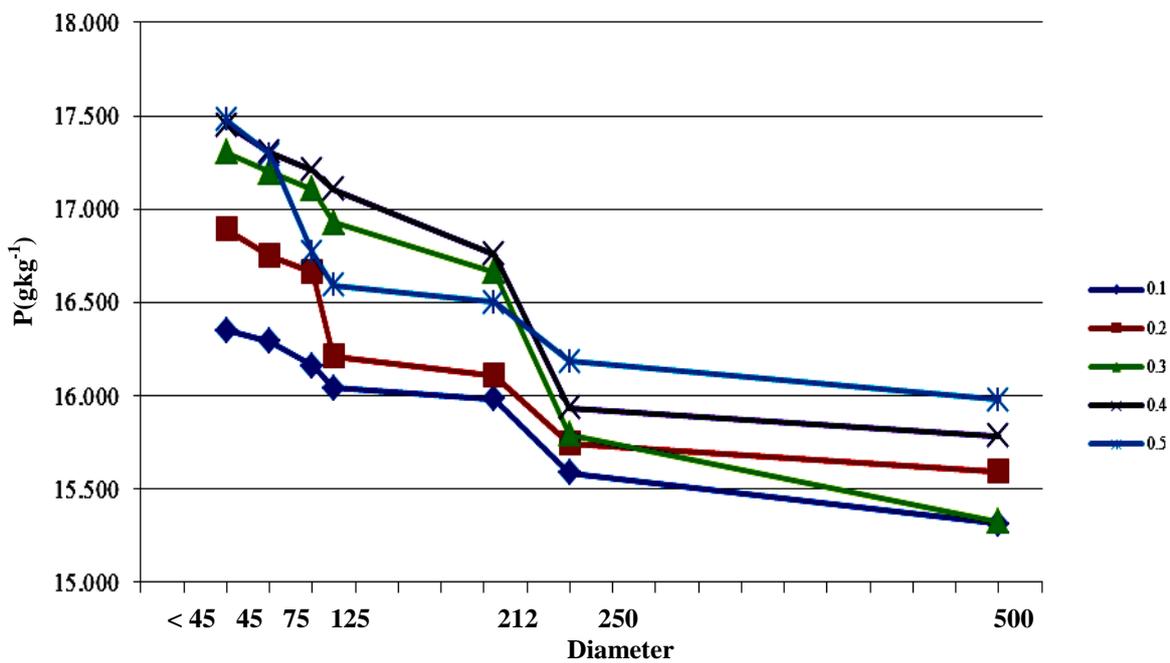
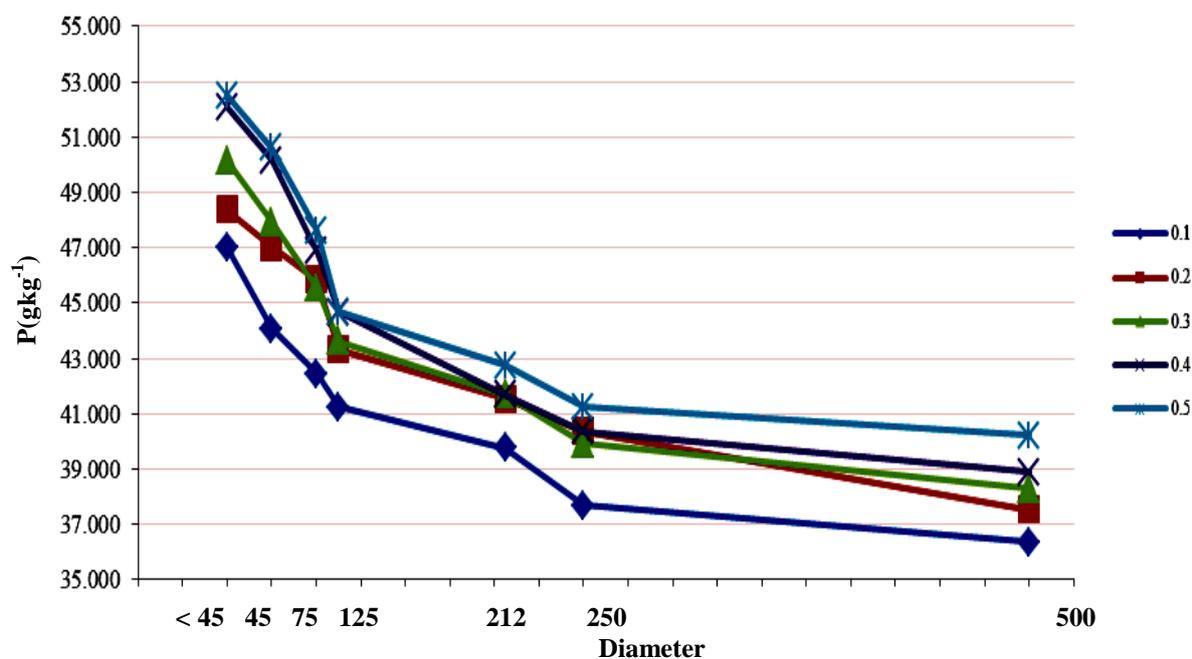


Fig. 7. Available P (gkg<sup>-1</sup>) of different phosphate rocks particles C- Tri calcium phosphate

**Table 6. Citric acid soluble P ( $\text{g kg}^{-1}$ ) in different particle-size fractions of PR sources and tricalcium phosphate using different sample weights (extractant per sample=100 ml)**

Weight of sample (g)	Diameter ( $\mu\text{m}$ )							Mean
	500	250	212	125	75	45	<45	
<b>A- Abou Tartour</b>								
0.1	36.37	37.70	39.78	41.26	42.45	44.08	47.04	41.24
0.2	37.55	40.37	41.56	43.34	45.86	47.04	48.38	43.44
0.3	38.30	39.93	41.71	43.63	45.56	47.93	50.16	43.89
0.4	38.89	40.37	41.71	44.67	46.89	50.16	52.08	44.97
0.5	40.22	41.26	42.74	44.67	47.64	50.60	52.53	45.67
Mean	38.27	39.93	41.50	43.51	45.68	47.96	50.04	43.84
<b>B- El-Sibaia Gharb</b>								
0.1	27.03	28.81	29.70	31.92	33.11	33.55	34.59	31.24
0.2	27.47	29.10	29.99	32.51	33.70	35.92	36.66	32.20
0.3	30.88	32.22	35.33	36.81	38.15	38.15	38.59	35.73
0.4	31.62	32.66	33.85	36.66	39.19	40.07	40.37	36.35
0.5	32.51	34.29	35.63	37.70	39.93	41.56	41.56	37.60
Mean	29.90	31.42	32.90	35.12	36.81	37.85	38.35	34.62
<b>C- Tri Calcium Phosphate</b>								
0.1	na	74.92	76.84	78.18	79.81	80.40	80.99	78.52
0.2	na	75.81	76.84	79.07	80.40	81.74	82.92	79.46
0.3	na	75.81	76.84	79.66	81.74	82.33	83.96	80.06
0.4	na	76.55	77.29	79.66	81.29	83.07	83.96	80.30
0.5	na	78.62	80.40	81.74	82.77	83.66	84.55	81.96
Mean	na	76.34	77.64	79.66	81.20	82.24	83.28	80.06

na : Non-applicable since the tricalcium phosphate salt was of a diameter of 250  $\mu\text{m}$  or less.



**Fig. 8. Citric acid-Soluble P ( $\text{g kg}^{-1}$ ) of different phosphate rocks particles A- Abou Tartour**

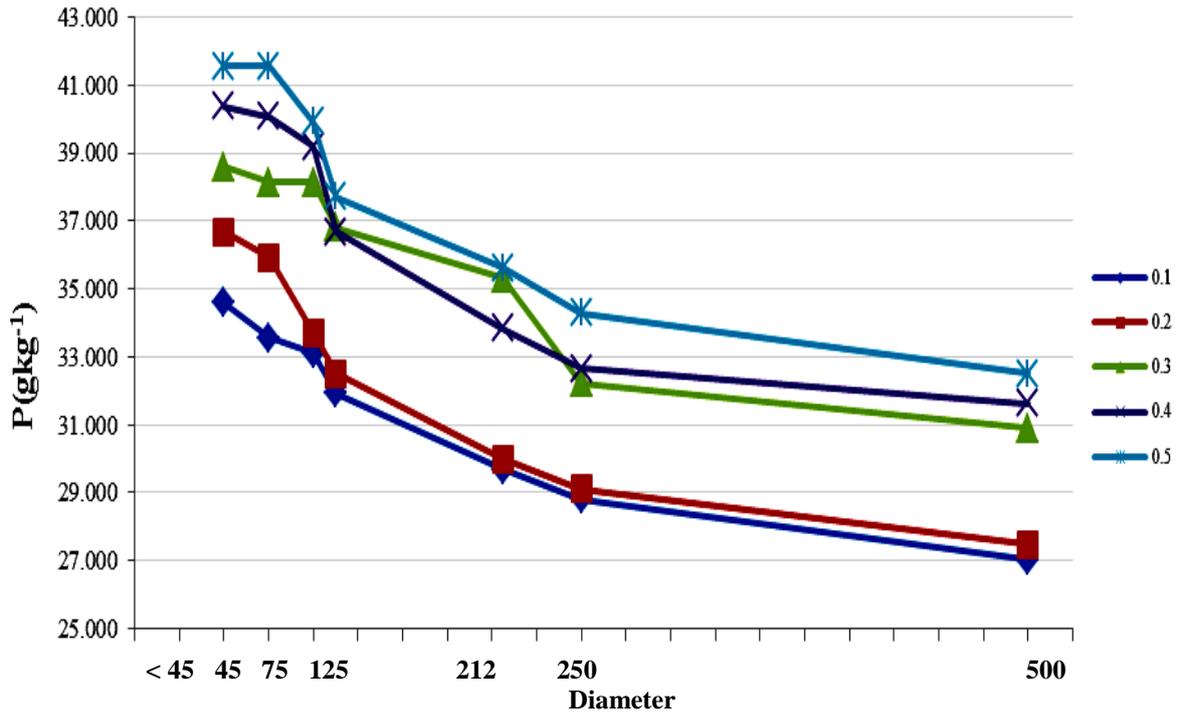


Fig. 9. Citric acid-Soluble P (gkg<sup>-1</sup>) of different phosphate rocks particles B- El-Sibaia Gharb

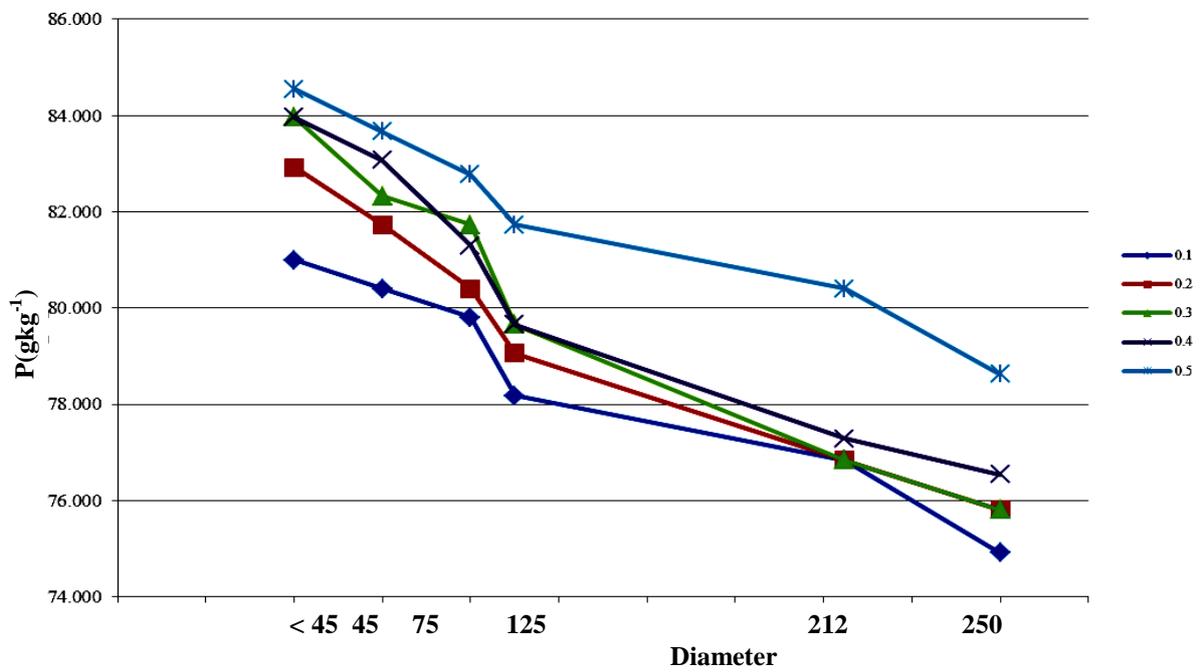


Fig. 10. Citric acid-Soluble P (gkg<sup>-1</sup>) of different phosphate rocks particles C- Tri calcium phosphate

### Experiment 2 (Comparative P-solubility by organic acids)

Extractable P was the highest using citric acid and the lowest using oxalic acid. The pattern was as follows: citric > formic > tartaric > acetic > oxalic for Abou Tartour PR and citric > formic > tartaric > acetic > oxalic for El-Sibaia Gharb PR. A trend of increasing extraction with decreasing the particle size is shown (Table 7 and Figs. 11 and 12). These results agree with findings by Dinkelaker *et al.* (1989), Hoffland (1992), Hoffland *et al.* (1992) and Al-Oud (2011) who noted that acid extraction using citric acid gives more P than other extractions using organic acids such as oxalic acid. The data also show that there was a high increase for the 250 and 125  $\mu\text{m}$  diameters.

The oxalic acid showed that the highest relative increase (146%) occurred due to the decrease in particle size.

To study the possibility of using low molecular weight organic acids as an indicator for available P, the statistical analysis showed significant correlation between the organic acids used and available P, determined by Olsen (1956) method. The organic acids can be arranged due to correlation coefficient as following: oxalic (0.84); tartaric (0.865); acetic (0.826); formic (0.749) and citric acid (0.397) for Abou Tartour.

In addition to El-Sibaia Gharb the correlation coefficients were acetic (0.959); oxalic (0.941); tartaric (0.917); formic (0.759) and citric acid (0.716).

**Table 7. Soluble P ( $\text{gkg}^{-1}$ ) extracted by low molecular weight organic acids**

Acid		Diameter( $\mu\text{m}$ )							Mean
		500	250	212	125	75	45	<45	
<b>A- Abou Tartour</b>									
<b>Formic</b>	<b>2%</b>	39.3	40.1	41.1	42.3	43.0	43.6	44.2	42.0
<b>Acetic</b>	<b>2%</b>	36.1	36.8	37.9	38.4	39.6	41.0	41.3	38.7
<b>Tartaric</b>	<b>2%</b>	36.8	39.2	41.7	44.1	45.9	48.2	49.0	43.5
<b>Oxalic</b>	<b>2%</b>	19.0	21.1	22.9	24.5	25.5	26.6	27.8	23.9
<b>Citric</b>	<b>2%</b>	40.2	41.3	42.7	44.7	47.6	50.6	52.5	45.7
	<b>Mean</b>	34.3	35.7	37.3	38.8	40.3	42.0	43.0	38.8
<b>B- El-Sibaia Gharb</b>									
<b>Formic</b>	<b>2%</b>	31.3	31.8	32.5	33.7	35.2	36.5	38.1	34.2
<b>Acetic</b>	<b>2%</b>	25.7	26.4	27.5	28.7	29.5	30.7	32.4	28.7
<b>Tartaric</b>	<b>2%</b>	27.1	28.6	30.9	32.1	33.1	34.1	35.8	31.7
<b>Oxalic</b>	<b>2%</b>	14.4	15.9	17.4	19.0	20.8	22.0	23.5	19.0
<b>Citric</b>	<b>2%</b>	32.5	34.3	35.6	37.7	39.9	41.6	41.6	37.6
	<b>Mean</b>	26.2	27.4	28.8	30.2	31.7	33.0	34.3	30.2

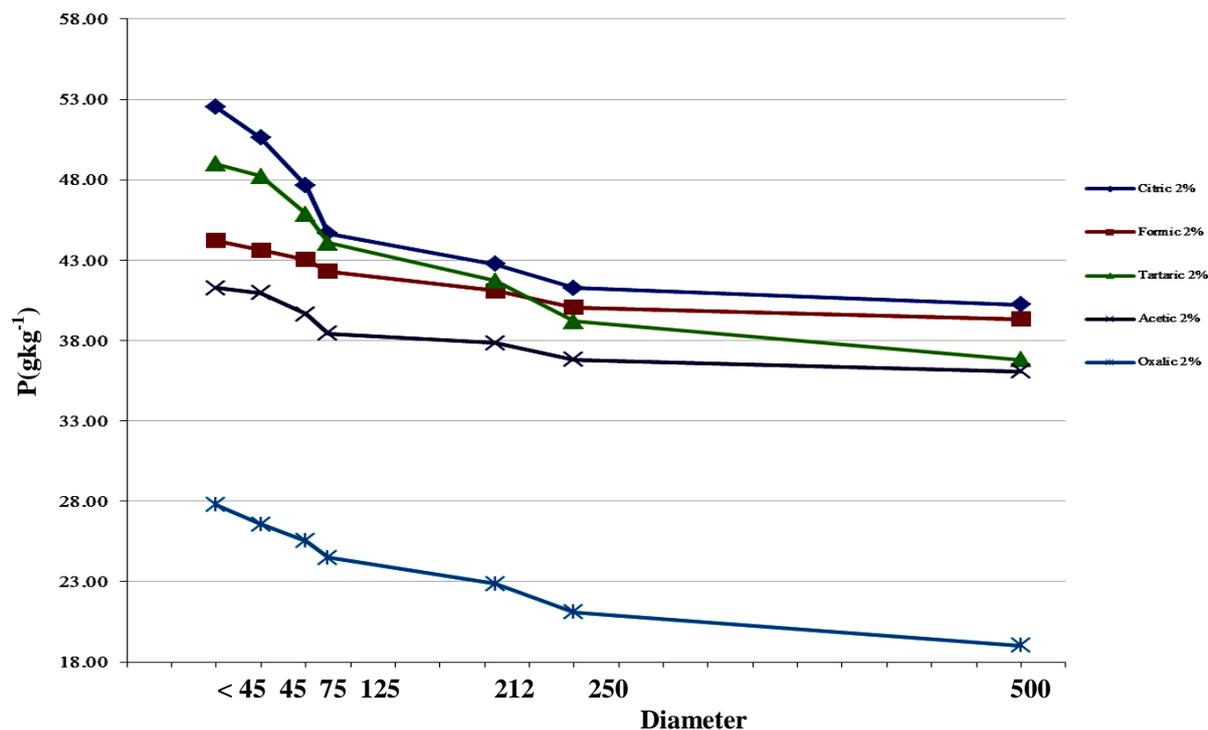


Fig. 11. Soluble P (gkg<sup>-1</sup>) extracted by low molecular weight organic acids as affected by particle size A- Abou Tartour

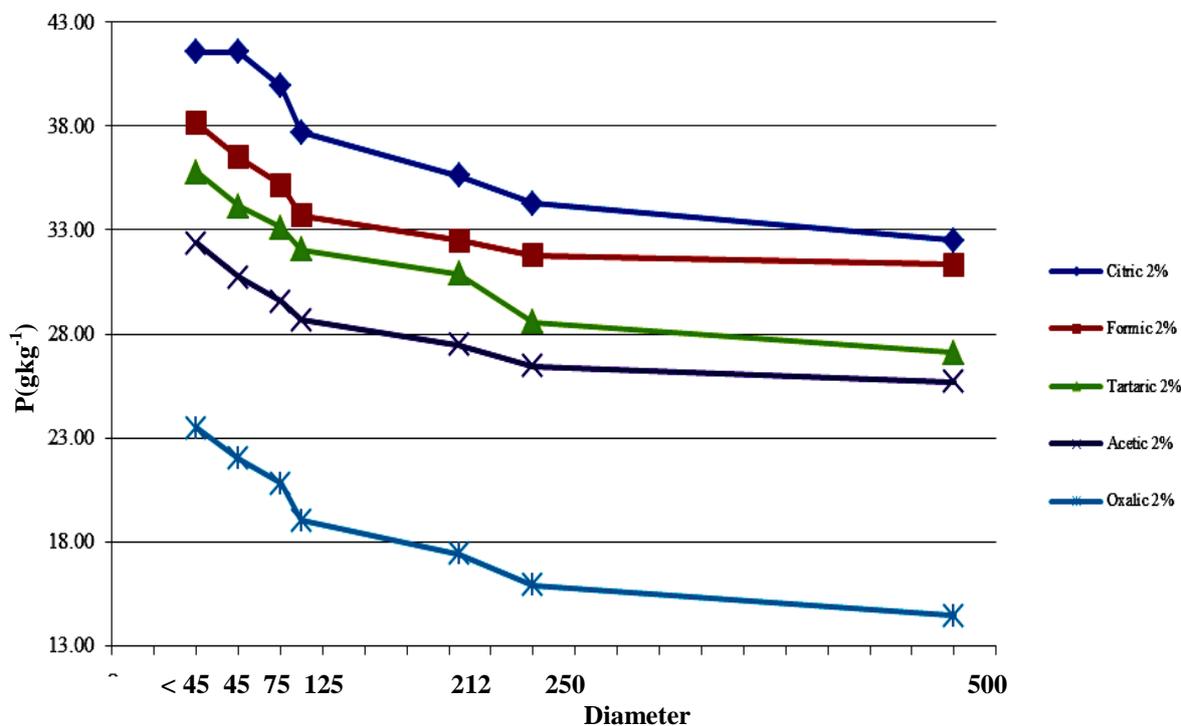


Fig. 12. Soluble P (gkg<sup>-1</sup>) extracted by low molecular weight organic acids as affected by particle size B- El-Sibaia Gharb

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## طرق متكاملة لزيادة ذوبانية صخر الفوسفات

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أجريت مجموعة من التجارب المعملية لدراسة تأثير بعض العوامل المتكاملة على ذوبان صخر الفوسفات والفوسفات ثلاثي الكالسيوم حيث كان صخر الفوسفات من موقعي دراسة وهما أبو طرطور والسباعية غرب، حيث تم طحن عينات صخر الفوسفات إلى حبيبات ذات قطر أقل لتعبر من منخل ذو قطر ١.١٨ ملليمتر، وقد تم فصلها إلى ٧ أقطار مختلفة وهي ٥٠٠، ٢٥٠، ٢١٢، ١٢٥، ٧٥، ٤٥، >٤٥ ميكروميتر تم التعرف على العينات وتقسيمها من خلال استخدام المسح بالميكروسكوب الإلكتروني وكذلك حيود أشعة اكس، تم تقييم ذوبان صخر الفوسفات بالماء المقطر وكذلك استخدام ٥ أحماض عضوية مختلفة وهي الفورميك، الخليك، الطرطريك، الأوكساليك والسيتريك بتركيز ٢%، حيث يوجد الفوسفور في المصدر الأول أبو طرطور على هيئة فوسفات كالسيوم هيدروكسيد والتركيب البلوري يوجد على هيئة أكسيد سليكون و كربونات كالسيوم وفوسفات أحادي الكالسيوم المائية، ويتواجد الفوسفور في المصدر الثاني السباعية غرب على هيئة البروسيت/ ويتراوح محتوى الفوسفور الذائب في الماء ما بين ٠.٢ إلى ٠.٦ جم/كجم، والمستخلص بطريقة أولسن يتراوح بين ١٠ إلى ١٧ جم/كجم، ويتراوح المستخلص بواسطة الأحماض العضوية للمصدرين المستخدمين من صخر الفوسفات ما بين ٣٩ إلى ٤٤ جم/كجم لحمض السيتريك، ٢٥ إلى ٤١ لحمض الخليك، ٢٧ إلى ٤٩ لحمض الطرطريك، ١٤ إلى ٢٨ لحمض الأوكساليك و ٣٢ إلى ٥٢ لحمض الفورميك، حيث وجد أن هناك زيادة تحدث في الفوسفور كلما قل حجم الحبيبات ويمكن الاستدلال بذلك من الناحية العملية على استخدام صخر الفوسفات مباشرة في التسميد.

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