4. RESULTS AND DISCUSSION

4.1. *Evaluation of the efficiency of soil tests commonly used for determining soil P availability*

Soil testing programs have been used in many countries to assess the nutrient status of soils or the availability of soil P and to determine P fertilizer recommendations (Bationo et al. 1991).

The relatively small amounts of phosphorus present in the soil solution is considered to be an immediate source of phosphorus for growing plants. Because this P form is subjected to continuous removal through plant P absorption, the contributing forms of soil P which are involved in the P equilibrium state in soil would be disturbed and phosphorus will be drawn from these forms to the region of equilibrium. A more realistic definition of the available phosphorus is the amount of labile phosphate that can contribute to the replenishment of phosphorus in the soil solution during plant growth (Holford 1980).

Available soil-phosphorus tests, however, should provide a quantitative measure of the degree to which each of the soil P fractions is related to plant available P.

Several authors have developed chemical methods using different extractants to determine the amount of available soil P (Bray and Kurtz, 1945 : Olsen et al. 1954 ; Colwell, 1963, Van der Paauw, 1971 and Simard et al. 1991).

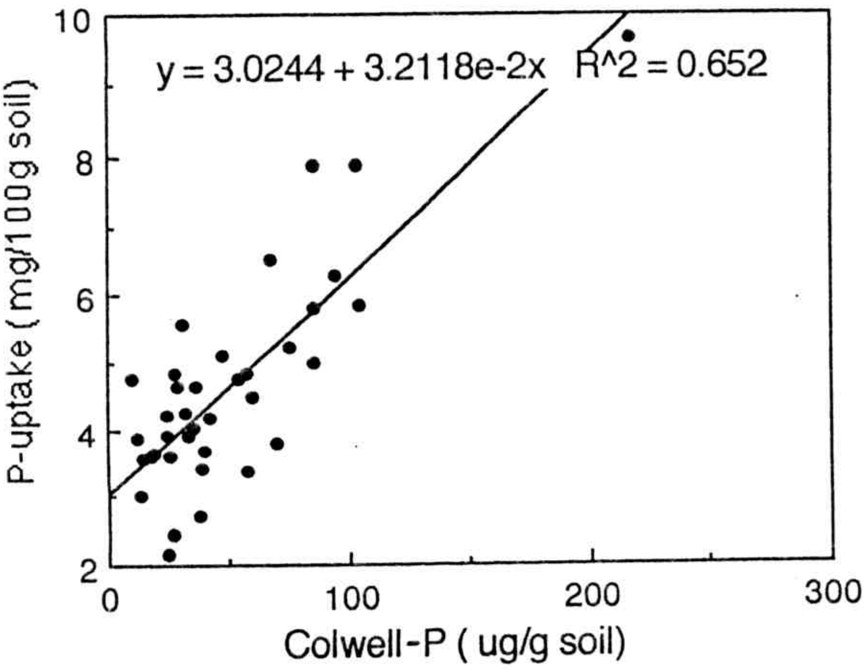
A good soil test for phosphorus is the one which extracts phosphorus from the same source as plant roots do. It should meet the following three criteria (i) extract all or a proportionate part of the available P form or forms from soils with variable properties, (ii) the amount extracted can be measured with reasonable accuracy and speed, and (iii) the amount extracted should be correlated with the growth and response of each crop to that nutrient under various conditions (Bray, 1948).

The main objective of this part of study is to investigate the sutiability of the different methods commonly used for extracting soil phosphorus, for assessing P availability to plants. To fulfill this objective, thirty nine soil samples classed to noncalcareous (<7% $CaCO_3$), Calcareous (<7% $CaCO_3$), heavy textured (>40% clay) and light textured (<40% clay) were collected from different locations in Egypt, (Northern Coast, Sinai, the Delta and the Nile Valley). Locations of soil samples are shown in map (1) and the general properties of the tested soils are shown in Table (1).

Eleven methods of P extraction were used, namely; Olsen, Colwell, anion-exchange resin (AER), 0.01 M $CaCl_2$ solution, distilled water at different ratios, ^{32}P-exchange technique (labile), Sr-citrate, Bray-1 and Bray-2 , Table (2), Phosphorus uptake was determined using Neubauer technique using rye as indicator plants. The mean values of P extracted through the different extractants used in this study and the values of P taken up by rye plants are shown in Table (3) and graphically illustrated

Table (3): Data of soil phosphorus fractions extracted by different methods from the investigated soils (ug/g).

Soil No.	Soil location	Olsen P	AER P	$Bray_1$ P	$Bray_2$ P	Labile P	$CaCl_2$ P	H_2O-P (1:5)	H_2O-P (1:60)	H_2O-P (1:250)	Sr-citr. P	Colweel P	P-uptake mg/100g soil
	(1) Heavy textured soils:												
	(a) Calcareous soils:												
1	Ebees	15.8	19.8	0.9	36.5	26.8	0.5	0.2	4.9	12.1	14.7	40.1	3.69
2	Kafer El-Dawar	7.6	18.0	0.5	28.4	35.5	0.4	0.2	10.8	12.1	9.6	24.7	2.16
3	Housh Essa	55.8	51.2	0.7	121.7	62.5	2.8	1.8	22.7	32.8	20.0	94.7	6.30
4	El-Amerya (A)	158.2	97.3	1.9	18.5	83.0	9.7	5.9	40.7	52.7	18.0	216.2	9.66
	(b) Non-Calcareous soils:												
5	Moshtohor	43.2	61.9	24.7	300.2	77.9	2.9	2.2	35.0	31.8	48.0	85.4	7.87
6	Fayoum	60.1	60.4	16.3	219.0	73.3	3.1	2.5	30.2	20.0	51.7	102.9	7.89
7	El-Hamoul	25.4	23.8	5.2	137.9	56.3	0.7	0.1	7.6	24.5	26.1	59.7	4.52
8	Shalma	30.5	32.3	6.3	139.9	43.1	0.4	0.9	7.6	6.7	19.5	38.4	3.42
9	Menia El-Kamh	49.4	36.6	8.4	225.1	61.2	1.6	1.0	13.2	25.4	41.6	86.0	5.03
10	Meet-Gamr	15.3	21.0	7.1	180.5	31.0	0.6	0.6	12.9	16.9	22.7	27.1	2.43
11	Etay El-Baroud	25.4	32.6	18.4	113.6	46.9	2.0	1.1	18.5	27.3	29.0	54.2	4.77
12	Tanta	34.1	49.1	25.7	186.5	64.5	2.5	1.4	24.6	27.6	36.3	75.1	5.24
13	Kafer El-Zayat	22.1	40.6	10.0	194.7	49.7	0.9	0.7	16.0	29.9	28.3	57.6	4.86
14	Damanhour	10.8	25.6	1.1	97.4	27.6	0.5	0.4	11.2	14.0	19.0	27.3	4.85
	(2) Light textured soils:												
	(a) Calcareous soils:												
15	Ganaklies (B)	14.5	12.2	0.1	30.9	16.7	0.6	0.3	9.9	16.5	10.8	31.9	4.28
16	El-Amerya (B)	88.9	64.1	2.2	1.8	60.6	2.6	3.5	24.5	37.3	8.5	104.7	5.86
17	Burg El-Arab (A)	24.2	21.0	0.5	5.4	24.1	0.7	0.4	7.4	25.3	5.0	38.1	2.68
18	Burg El-Arab (B)	18.9	12.8	0.1	8.2	16.6	0.5	0.2	1.8	12.1	9.7	45.8	-
19	West Noubaria (A)	4.4	4.3	0.1	18.8	6.3	0.6	0.3	4.9	8.9	6.0	25.9	3.63
20	West Noubaria (B)	9.9	4.0	0.6	46.6	11.0	0.6	0.4	2.0	14.9	12.1	35.5	4.03
21	East Noubaria	9.3	9.4	0.2	24.3	12.7	0.6	0.1	8.2	14.9	10.0	24.7	4.24
22	El-Henwa	29.3	32.3	0.5	2.5	23.1	1.2	0.4	7.5	21.5	12.7	47.4	5.14
23	El-Mazraa	21.4	10.4	0.6	0.2	20.6	0.5	0.2	2.0	11.7	9.3	37.1	4.67
24	El-Satah	7.7	6.1	0.1	2.0	22.2	0.1	0.2	9.0	12.8	-	57.5	3.39
25	Wadi Sidr	7.1	12.2	0.1	0.1	34.2	0.4	0.2	4.2	9.0	4.6	18.5	3.67
26	Wadi Sidri	2.6	3.1	0.1	0.3	45.7	0.4	0.1	0.8	5.8	3.2	12.9	3.01
27	Wadi Araba El-Soghie	4.3	9.8	0.7	20.3	20.6	0.5	0.2	0.9	12.5	8.6	14.4	3.58
28	Wadi El-Awag	2.3	6.4	0.1	79.1	9.5	0.1	0.1	6.5	6.4	6.6	11.8	3.90
29	Wadi Mehash	2.6	3.7	0.9	17.7	10.0	0.4	0.3	4.6	15.4	8.5	32.9	3.92
30	Wadi Abu-Gerf	2.2	4.3	2.2	30.9	7.1	0.0	0.1	4.1	16.0	9.3	17.7	3.61
	(b) Non-Calcareous soils:												
31	Meet-Kenana (A)	26.6	27.8	41.5	180.5	28.4	2.8	3.3	18.6	25.4	21.3	30.9	5.58
32	Meet-Kenana (B)	6.8	21.4	49.9	195.5	10.9	0.4	0.4	8.4	23.3	8.2	10.3	4.78
33	El-Dair	8.8	24.4	13.6	235.3	27.2	0.5	1.1	11.2	8.6	25.6	24.7	3.95
34	Benha (A)	118.4	137.8	97.6	231.2	31.7	0.7	9.8	11.6	9.2	18.4	30.2	-
35	Benha (B)	14.4	16.5	10.7	119.7	149.4	9.0	0.7	85.5	89.7	33.6	85.3	5.81
36	Quesna	39.7	39.7	32.5	257.6	53.4	3.0	3.3	26.1	25.4	43.0	67.9	6.53
37	Giza	17.1	25.0	13.6	194.7	34.0	0.6	1.5	13.2	7.0	29.5	42.2	4.22
38	Kom Ambo	6.9	5.8	1.1	109.5	14.7	0.8	0.4	4.4	14.4	13.3	28.5	4.66
39	Ganaklies (A)	20.3	25.0	0.4	125.7	24.0	0.9	1.9	15.5	22.3	-	-	3.95



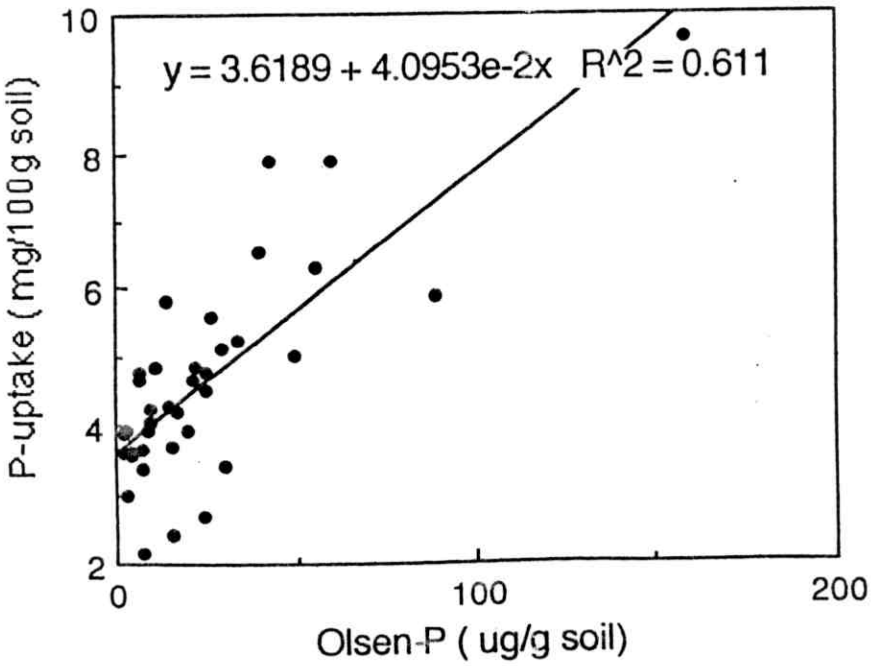


Fig. (2). The relationship between NaHCO3-extractable P (µg/g soil) and P uptake by rye plants (mg/100 g soil).

in Figures (1, 2, 3, 4 and 5).

4.1.1. Extraction of soil available phosphorus with $NaHCO_3$

The data obtained in Table (3) and illustrated in Fig (2) show that the values of soil phosphorus extracted by 0.5 M $NaHCO_3$ solution of Olsen et al., (1954) range from 2.2 to 158.2 ppm with an average of about 26.31 ppm.

The results obtained by using Colwell method (1963), which is a modified type of Olsen one only by extending the time of equilibration to 16 hours and widing the ratio of soil-water to 1:100, are comparable and ranging between 11.8 and 216.2 ppm with an average of 50.58 ppm.

The data may indicate that the category of the heavy textured soils tends to show relatively higher values of available phosphorus than the other tested soil categories (light textured, noncalcareous and calcareous soils). The average values of phosphorus extracted from the noncalcareous, calcareous, heavy textured and light textured soil categories by Olsen method were 30.3, 24.3, 39.5 and 20.3 ppm, respectively. The corresponding values achieved by Colwell method were 51.9, 46.6, 70.7 and 36.5 ppm, respectively. Similar results were obtained by Abd El-Aal (1975), who found that phosphorus extracted by Olsen method from heavy textured soils tended to show relatively higher values than both sandy and calcareous soils.

Statistical analysis (Table 4) indicates that extraction of available phosphorus by the $NaHCO_3$ methods correlated signifi-

Table (4): Values of correlation coefficient between soil P extracted by different methods and P-uptake by rye plants.

Tested soil	Olsen P	AER P	Bray 1 P	Bray 2 P	Labile P	$Cacl_2$ P	H_2O-P (1:5)	H_2O-P (1:60)	H_2O-P (1:250)	Sr-citr. P	Colwell P
All the tested soils	0.775***	0.803***	0.323*	0.337*	0.607***	0.746***	0.797***	0.610***	0.557***	0.556***	0.830***
Non-Calcareous soils (<7% $CaCO_3$)	0.639**	0.677**	0.355	0.466*	0.477*	0.516*	0.618**	0.482*	0.350	0.710***	0.700***
Calcareous soils (>7% $CaCO_3$)	0.908***	0.865***	0.481*	0.118	0.758***	0.913***	0.891***	0.851***	0.839***	0.674***	0.923***
Soils containing >40% clay	0.819***	0.934***	0.289	0.203	0.868***	0.838***	0.862***	0.893***	0.781***	0.491	0.877***
Soils containing <40% clay	0.597***	0.634***	0.506**	0.444*	0.566**	0.642***	0.710***	0.585**	0.539**	0.636***	0.681***

*Where *, **, *** significant at 0.05, 0.01 and 0.001 level, respectively.*

cantly with plant P uptake. The simple correlation coefficient (r) values were 0.830 for the Colwell method and 0.775 for the Olsen one.

The superiority of Colwell test over Olsen one may be attributed to the longer time used in equilibrating the soils with the extracanting solution in the former method that is, in turn, reflected on the amount of P extracted by this method to become almost two times as much soil available phosphorus as the Olsen one. This finding is in accordance with that of Bowman et al. (1978). The Olsen method may underestimate available phosphorus by dissolving phosphorus less than plant absorbs. Such results coincide with Olsen et al., (1954) who concluded that the Olsen method was primarly designed to evaluate plant available phosphorus in calcareous soils and removes about half of the surface-adsorbed phosphorus (available phosphorus). These results were confirmed by those of Bowman et al. (1978) who revealed that the Olsen method extracts 50% of the available phosphorus while the Colwell method extracts nearly 80% of the available phosphorus from calcareous and neutral soils. However, Olsen method has been extensively tested more than Colwell method (the more recent) and many workers confirmed the reliability of the Olsen method for assessing the availability of soil P in alkaline and calcareous soils. Among these investigators, Mattingly et al. (1963), Alban (1972), Sharpley et al. (1987) and Sharpley et al. (1989), and in Egypt, Omar (1957), El-Rashidi (1972), Abd El-Aal (1975) and Abbas (1980) **are reported** .

Concerning the different soil categories, data of statistical analysis presented in Table (4) reveal that the "r" values representing the relationship between $NaHCO_3$-extractable phosphorus and P-uptake of the different investigated soil categories (the noncalcareous, calcareous, heavy textured and light textured soils) were 0.700, 0.923, 0.878 and 0.681, respectively for the Colwell test while the corresponding values obtained for Olsen were 0.639, 0.908, 0.819 and 0.597, respectively.

Such results show a quite reliability of bicarbonate solution particularly as recommended by Colwell (1963) as an extractant of available P in highly calcareous soils followed by the heavy textured ones. However, in all soil categories,'r' values were highly significant and in all cases they were higher with the Colwell test than with the Olsen one. Bowman et al. (1978) indicated that the Colwell modification of the Olsen test correlated better with the labile P pool as well as with plant P uptake rather than the original Olsen test.

With respect to the relationships between soil available P extracted by $NaHCO_3$ solution and different soil characteristics, Table (5) show that Colwell-P was significantly correlated with the soil organic matter content ($r = 0.558$) , clay content ($r = 0.382$) and surface area ($r = 0.325$). However, no significant correlation was achieved with the other studied soil characteristics.

On the other hand, Olsen extractable P correlated significantly only with the organic matter content ($r = 0.489$), and

Table (5): *Simple correlation coefficient between extractable-P by different methods and some soil characteristics.*

	Olsen P	AER P	Bray 1 P	Bray 2 P	Labile P	Cacl$_2$ P	H_2O-P (1:5)	H_2O-P (1:60)	H_2O-P (1:250)	Sr-citr. P	Colwell P
Clay	0.338 *	0.480 **	-0.002	0.388 *	0.399 *	0.108	0.177	0.147	0.108	0.507 **	0.382 *
pH	-0.284	-0.517 ***	-0.357	-0.643 ***	-0.390 *	-0.137	-0.350 *	-0.212	-0.071	-0.643 ***	-0.296
Soil O.M.	0.489 **	0.644 ***	0.135	0.410 *	0.604 ***	0.425 **	0.473 **	0.485 **	0.337 *	0.612 ***	0.558 ***
Fe-ox	0.055	0.237	0.077	0.471 **	0.508 **	0.121	-0.004	0.308	0.197	0.554 ***	0.180
Al-ox	0.119	0.375 *	0.179	0.671 ***	0.458 **	0.051	0.091	0.241	0.078	0.736 ***	0.224
Surface area	0.237	0.428 **	0.081	0.571 ***	0.449 ***	0.088	0.149	0.206	0.081	0.681 ***	0.325 *

*Where *, **, *** significant at 0.05, 0.01 and 0.001 level, respectively.*

the clay content (r = 0.338). Such results could be explained according to Olsen et al. (1983) who indicated that plant P uptake is larger in soils with higher clay content, in spite of soluble P is approximately equal, or even greater for soil with less clay content. This effect could be attributed to diffusion and buffer capacity, since both factors increased with increasing clay content in soils.

4.1.2. *Extraction of soil available phosphorus with Sr-Citrate method:*

Sr-citrate solution was proposed by Simard et al. (1991) as an extractant for phosphorus that is supposed to be available for plants . This extractant is composed of 0.02 M $SrCl_2$ + 0.05 M citric acid. Citrate ions replace the phosphate ones from the soil sorbing surfaces.

Samples representing the four categories of soils , namely ; the noncalcareous , calcareous , heavy textured and light textured were subjected to extraction of available phosphorus by means of the Sr-citrate method as proposed by Simard (1991) and the obtained data are shown in Table (3) and illustrated in Fig (3) .

The data show that values of the phosphorus extracted by Sr-citrate ranged between 3.2 and 51.7 ppm with a general average of 19.3 ppm . Results showed a wide variation in values of the phosphorus extracted from soils of the different categories where they averaged 28.6 , 9.8 , 27.5 and 13.8 ppm P in the noncalcar-

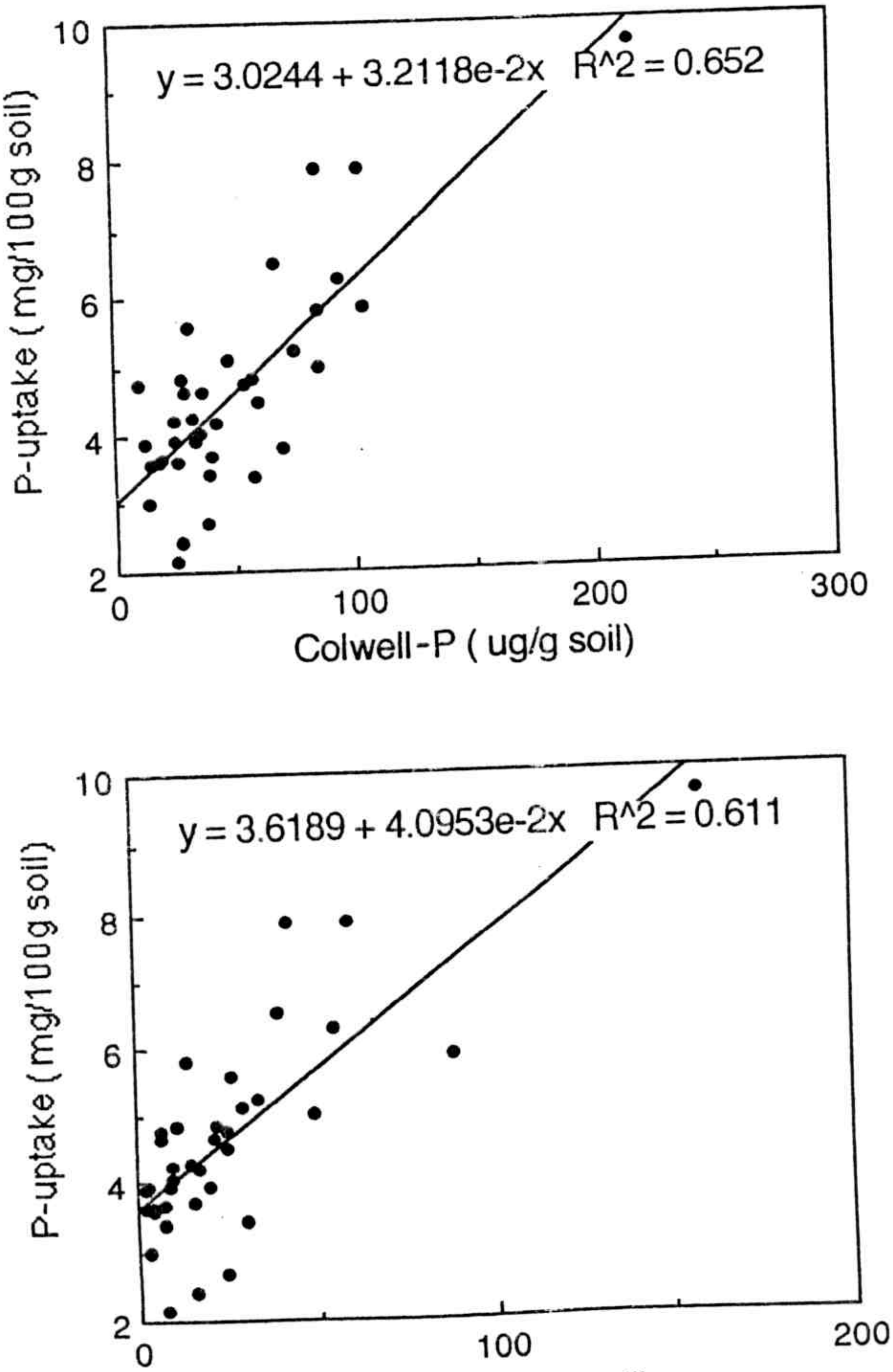


Fig. (2). The relationship between NaHCO3-extractable P (µg/g soil) and P uptake by rye plants (mg/100 g soil).

eous, calcareous , heavy textured and light textured soils , respectively . Such trend may indicate that soil phosphorus availability decreased with increasing the $CaCO_3$ content and soil content of the clay fraction. This finding is confirmed by values of the correlation coefficient "r" presented in Table (5) which reveal positive and high significant relationships between phosphorus extracted by this method and soils content of clay (r = 0.507) , organic matter content (r = 0.612) , Fe-ox (r = 0.554) , Al-ox (0.736) and surface area (r = 0.68) . However, a negative, but highly significant relationship was achieved with the soil pH values (r = -0.643).

Data of statistical analysis (Table 4) show that the Sr-citrate procedure , generally , could be considered among the best methods for predicting soil phosphorus availability . The reliability of this method was ensured by the high significant correlation obtained between Sr-citrate - extracted P and phosphorus uptake by the rye plants (r = 0.556). These results are similar to those of Simard et al., (1991) who reported that extracting solutions containing citrate , bicarbonate , acetate , EDTA and fluoride ions are able to from complexes with polyvalent cations and to be involved in ligand-exchange reactions with $HPO_4^{=}$ ions adsorbed by inner-sphere surface of comlexations.

Kamprath and Watson (1980) reported that, assuming that a lignad-exchne reaction is involved , it is possible that both citrate (Sr-citrate method) and bicarbonate (Olsen method) act in a comparable manner in displacing the orthophosphate ions from the adsorptive sites on $CaCO_3$ and hydrated oxides of Fe and Al without involving intensive dissolution reactions.

With respect to suitability of the Sr-citrate method for predicting the availability of phosphorus in the different categories of the tested soils, data of the statistical analysis presented in Table (4) show that phosphorus extracted by this method correlated significantly with phosphorus uptake by rye plants grown on the noncalcareous ($r = 0.710$) , calcareous ($r = 0.674$) and the light textured soils ($r = 0.636$). However, the relationship between the two variables was not significant in the category of the heavy textured soils ($r = 0.491$).

4 .1 . 3 . *Extraction of soil available phosphorus with 0.01 M $CaCl_2$:*

Data presented in Table (3) and Fig (4) show that values of soil phosphorus extracted by the 0.01 M $CaCl_2$ solution are ranging between traces and 9.7 ppm with an average of 1.57 ppm P . It is obvious that values of phosphorus extracted by this extractant (0.01 M $CaCl_2$ solution) were the lowest as compared to the values of phosphorus extracted by the other investigated ones. Mean values of the phosphorus extracted by this procedure from the noncalcareous , calcareous , heavy textured and light textured soils were 1.8 , 1.2 , 2.0 and 1.1 ppm , respectively.

Data of the statistical analysis presented in Table (4) and illustrated in Fig (4) show a very high significant relationship

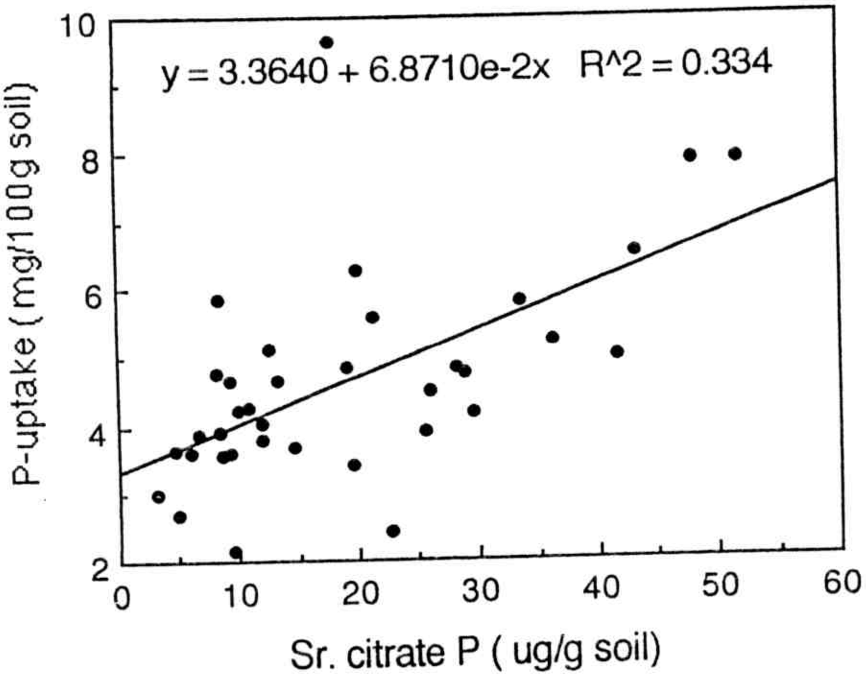


Fig. (3). The relationship between Sr-citrate extractable P (µg/g soil) and P uptake by rye plants (mg/100 g soil).

(r = 0.746) between phosphorus uptake by rye plants and $CaCl_2$-extractable phosphorus from the investigated soils as a whole . These results are almost similar to those of Olsen et al. (1983) who obtained a very close positive relationship between phosphorus taken up by plants and the phosphorus extracted by the 0.01 M $CaCl_2$ solution . On the other hand, El-Baz (1974) and Abd El-Aal et al., (1981) found no significant relationship between $CaCl_2$ - extractable phosphorus and phosphorus uptake by plants from some Egyptian calcareous soils .

Regarding the reliability of using the 0.01 M $CaCl_2$ solution for assessing phosphorus availability in the different categories of the investigated soils, it could be noticed that phosphorus uptake by plants correlated highly significantly with values of the phosphorus extracted from the calcareous, heavy textured and light textured soils where the "r" values obtained were 0.913, 0.834 and 0.642 , respectively . However, a lower level of significancy was obtained between the two variables in the category of the noncalcareous soils where the correlation coefficient "r" was only 0.516.

Testing the soil characteristics that might affect extractability of phosphorus by the 0.01 M $CaCl_2$ solution, data in Table (5) show a highly significant correlation between $CaCl_2$ -extractable phosphorus and organic matter content of soils (r = 0.425) but nosignificant relationship could be detected with the other soil characteristics.

4.1.4. *Extraction of soil available phosphorus with a dilute strong acid + a complexing ion:*

The dilute acid-fluoride procedure developed by Bray and Kurtz (1945) i.e., 0.03 M NH_4F + 0.025 M HCl (Bray-1) and 0.03 M NH4F+ 0.10 m HCl (Bray-2) , have been employed widely in assessing the availability of soil phosphorus. The complexing ion used in this respect is fluoride which complexes Al and Fe ions and consequently phosphorus releases.

The amounts of soil phosphorus extracted through Bray-1 method ranged from 0.1 to 97.6 ppm with an average of a 0.2 ppm, while the amounts extracted with Bray-2 one fluctuated between 0.1 and 300.2 ppm with an average of 111.0 ppm P, (Table 3).

Generally, Bray-2 method extracted the largest amount of the inorganic phosphorus from the tested soils of the four categories as compared with the other methods of extraction.

Data shown in Table (4) and Fig (5) indicate that the obtained values for phosphorus extracted by either Bray-1 or Bray-2 method were significantly correlated with phosphorus taken up by the rye plants (r = 0.323 and 0.337 , respectively). With respect to the different soil categories used in this study; the noncalcareous, calcareous, heavy textured and light textured soils ; "r" values between the two investigated variables were 0.355, 0.481, 0.289 and 0.506, respectively for Bray-1 method , corresponding to 0.466, 0.118, 203 and 0.444 for Bray-2 method. Such insignificancy or low correlation coefficient values achieved indicate that the reliability of such methods for

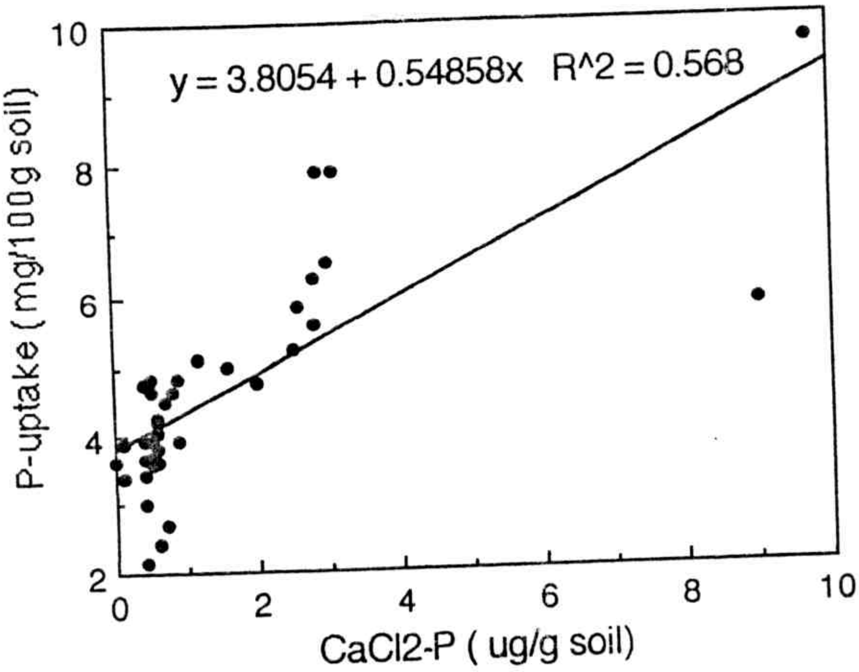


Fig. (4). The relationship between 0.01 M CaCl2 extractable P (µg/g soil) and P uptake by rye plants (mg/100 g soil).

4.1.5. *Extraction of soil available phosphorus with distilled water:*

Data in Table (3) and Fig (6) show the values of soil available phosphorus extracted by means of distilled water added to the soil samples at different soil-water ratios, namely, 1:5, 1:60 and 1:250.

It is obvious that the ability of distilled water (especially at the narrow soil : water ratio 1:5) to dissolve native P compounds is very much lower than the other extractants.

Average values of the extracted soil phosphorus by distilled water from the noncalcareous, calcareous, heavy textured and light textured soils were 1.7, 0.7, 1.3 and 1.2 ppm, respectively for the soil-water ratio (1:5) corresponding to 19.5, 8.9, 18.3 and 11.7 ppm for the soil-water ratio (1:60), and 23.6, 17.5, 23.8 and 18.6 ppm, respectively, for the soil-water ratio (1:250).

The data reveal also that the noncalcareous (<7% $CaCO_3$) and the heavy textured (>40% clay) soils, generally, contained higher values of water-soluble phosphorus than either of the calcareous (>7% $CaCO_3$) or the light textured(<40%clay) ones.

The correlation analysis between soil extractable phosphorus and phosphorus taken up by the rye plants (Table 4) indicates that values of the water-soluble P extracted at the different investigated soil : water ratios were highly significantly correlated with P-uptake by plants. The correlation coefficient values

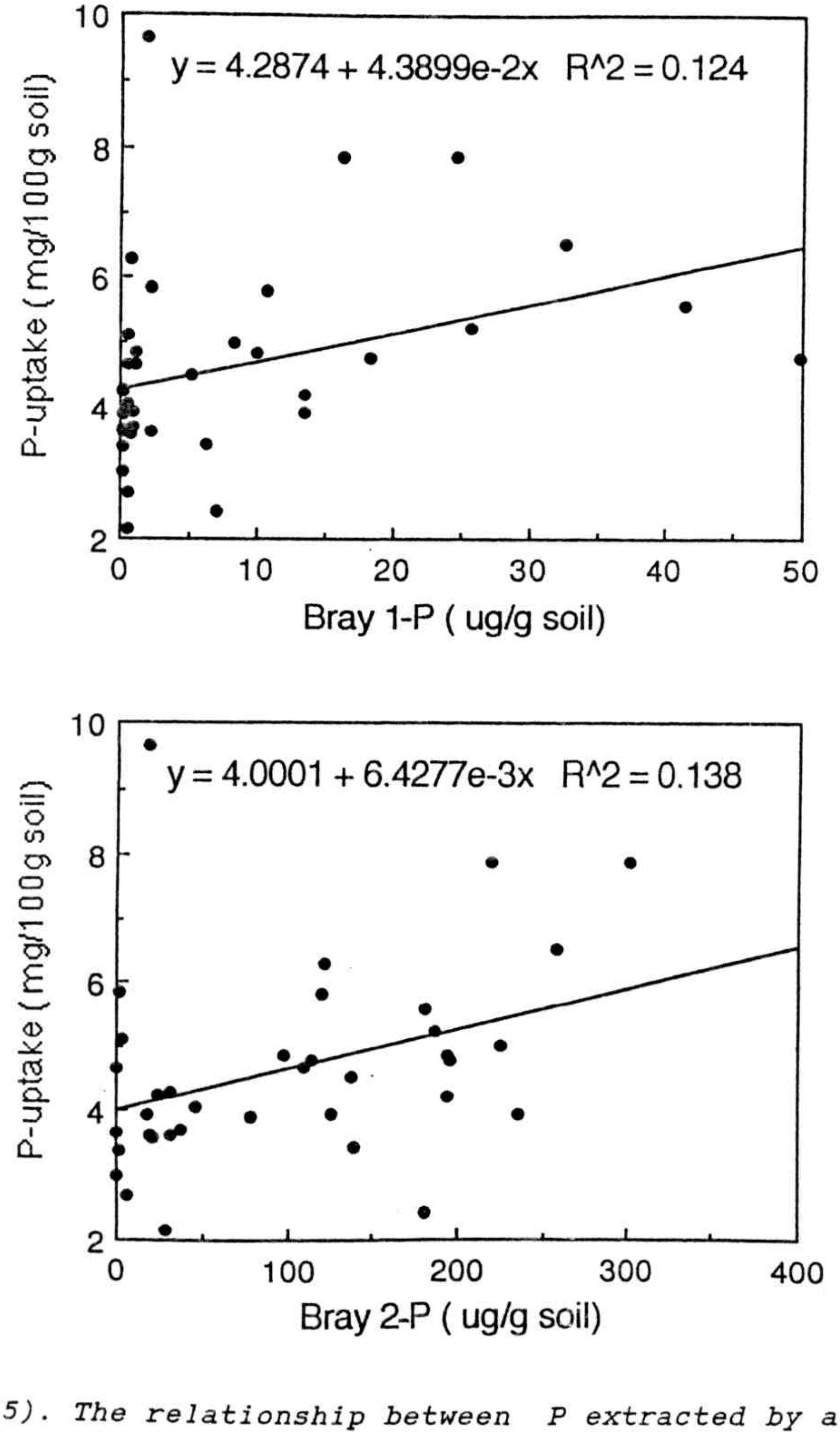


Fig. (5). The relationship between P extracted by a dilute strong acid + a complexing ion (µg/g soil) and P uptake by rye plants (mg/100 g soil).

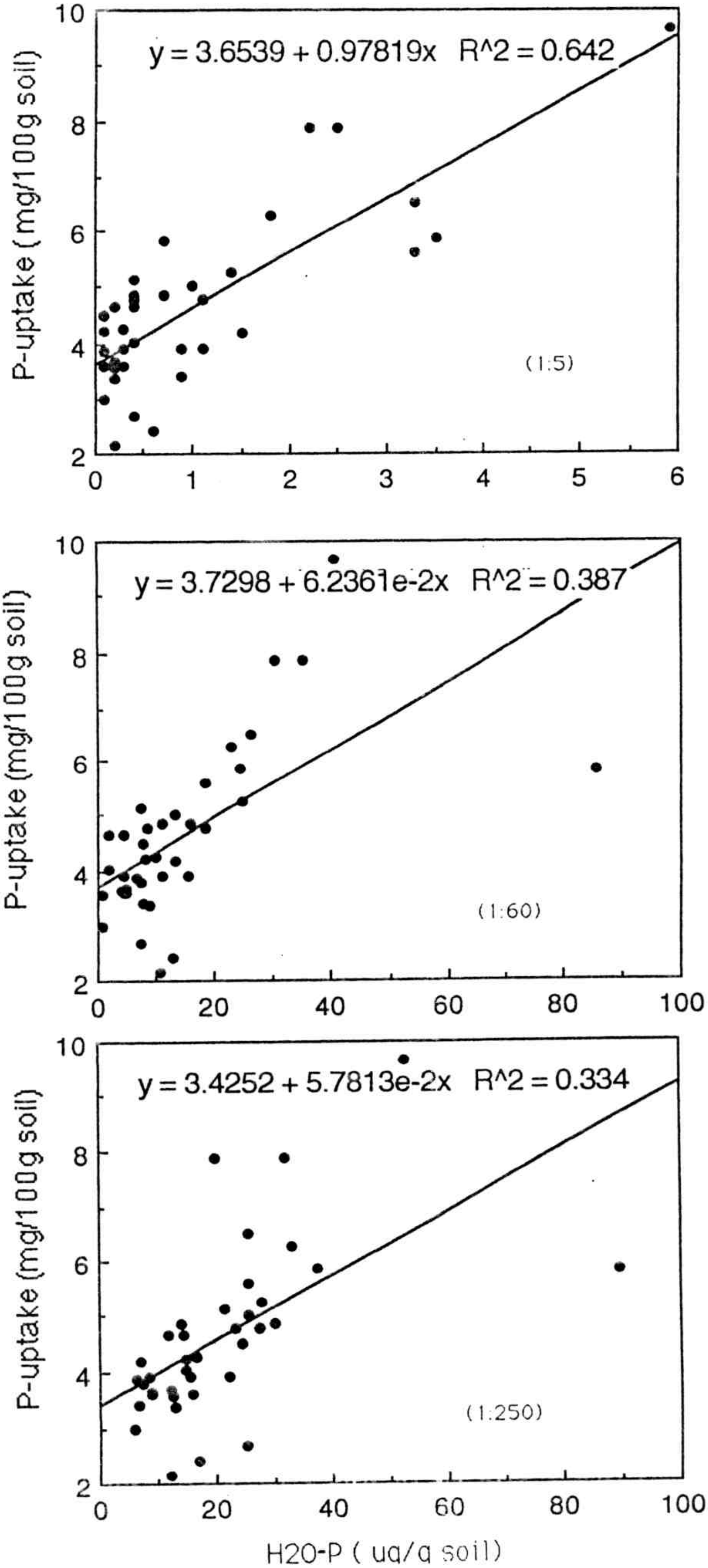


Fig. (6). The relationship between water soluble P (µg/g soil) and P uptake by rye plants (mg/100 g soil).

"r" were 0.797, 0.610 and 0.557 for the 1:5, 1:60 and 1:250 soil: water ratios, respectively.

It is obvious that the degree of significancy of the relationship between P-uptake and water-extractable P was increased as the soil-water ratio decreased, though the amount of water extractable P decreased. Similar trend was achieved by Abbas (1980) and confirmed by Abd El-Aal et al. (1981).

The obtained data show that distilled water, as a means of extracting soil P from the noncalcareous soil, was less successful as compared with its reliability in the calcareous soils.

It is also obvious that the widest ratio of extraction (1:250) failed to be correlated significantly with plant P uptake in the noncalcareous soils. However, this relation was significant with the narrower ratios, as the correlation coefficient raised, generally, in the following order 0.350 to 0.482 and then up to 0.618 with lowering the soil-water ratios from 1:250 to 1:60 and then up to 1:5, respectively.

This trend may be explained on a basis that the narrow soil: water ratios are more representative to the natural state of the soil than the wider ones and, hence, may reflect more accurately the soil solution behavior.

With respect to the calcareous soils, data obtained show that P-uptake by rye plants was high significantly related to water-soluble P extracted at all the different used soil-water ratios showing "r" values of 0.891, 0.851 and 0.839 for 1:5, 1:60 and 1:250 soil-water ratios, respectively. This trend is in accordance with that observed by Abbas (1980) upon his work on some Egyptian calcareous soils.

Regarding soil texture, a high significant relationship was obtained between P uptake in the heavy textured soils (> 40% clay) and water-extractable P at the tested soil : water ratios; 1:5, 1:60 and 1:250, with "r" values of 0.862, 0.893 and 0.781, respectively. These results ensure that the narrow soil : water ratios are more reliable than the wider ones in such soils, however, further investigations seemed to be required to determine more accurately the most suitable ratio for extracting soil available phosphorus.

In the light textured soils (<40% clay) a significant relationship was also achieved between P-uptake and water-extractable P . The "r" values obtained were 0.710 , 0.585 and 0.539 for the soil : water ratios 1:5, 1:60 and 1:250, respectively.

It is worthy to mention that the light textured soils showed the same general trend of the other soil categories where the 1:5 soil : water ratio was the most suitable tested ratio (r=0.710).

Values of simple correlation coefficient between phosphorus extracted by distilled water at the different soil-water ratios and some of the soil characteristics show that values of phosphorus extracted at the soil-water ratios 1:5 , 1:60 and 1:250 were significantly correlated with soil organic matter content with "r" values of 0.473 , 0.485 and 0.337 , respectively.

Significant, but negative, relationship was found between the pH values of the investigated soils and values of P extracted at the 1:5 soil-water ratio (r = 0.350) whereas the wider ratios (1:60 and 1:250) failed to show such relation.

Finally, results of the present work may give further evidence to the possibility of using distilled water, especially at narrow ratios (around 1:5) as an extractant of soil available phosphorus in soils of Egypt. This procedure is quite accurate , too-cheap and easy for performance . This conclusion stands in accordance with those reached by Soltanpour et al. (1974), Abd El-Aal (1975) and Abbas (1980) who recommended the use of 1:1 soil-water ratio as the most accurate ratio for extracting soil available phosphorus in the calcareous soils of Egypt.

4.1.6. *Evaluation of the exchangeable fraction of soil phosphorus:*

The isotopic dilution ^{32}P method has an advantage over the other chemical extractants because it does not disturb the soil components and there is an identity between the isotopically exchangeable P and the amount of phosphate absorbed by plants, Russell et al. (1954).

Data in Table (3) and Fig (7) show that the amount of labile phosphorus extracted by ^{32}P-exchange technique ranged from 6.3 to 149.4 ppm P with a general average of 38.3 ppm P . The labile P extracted from the different tested categories of soils averaged 47.6, 27.6 ,52.8 and 28.6 ppm for the noncalcareous , calcareous , heavy textured and light textured soils , respectively .

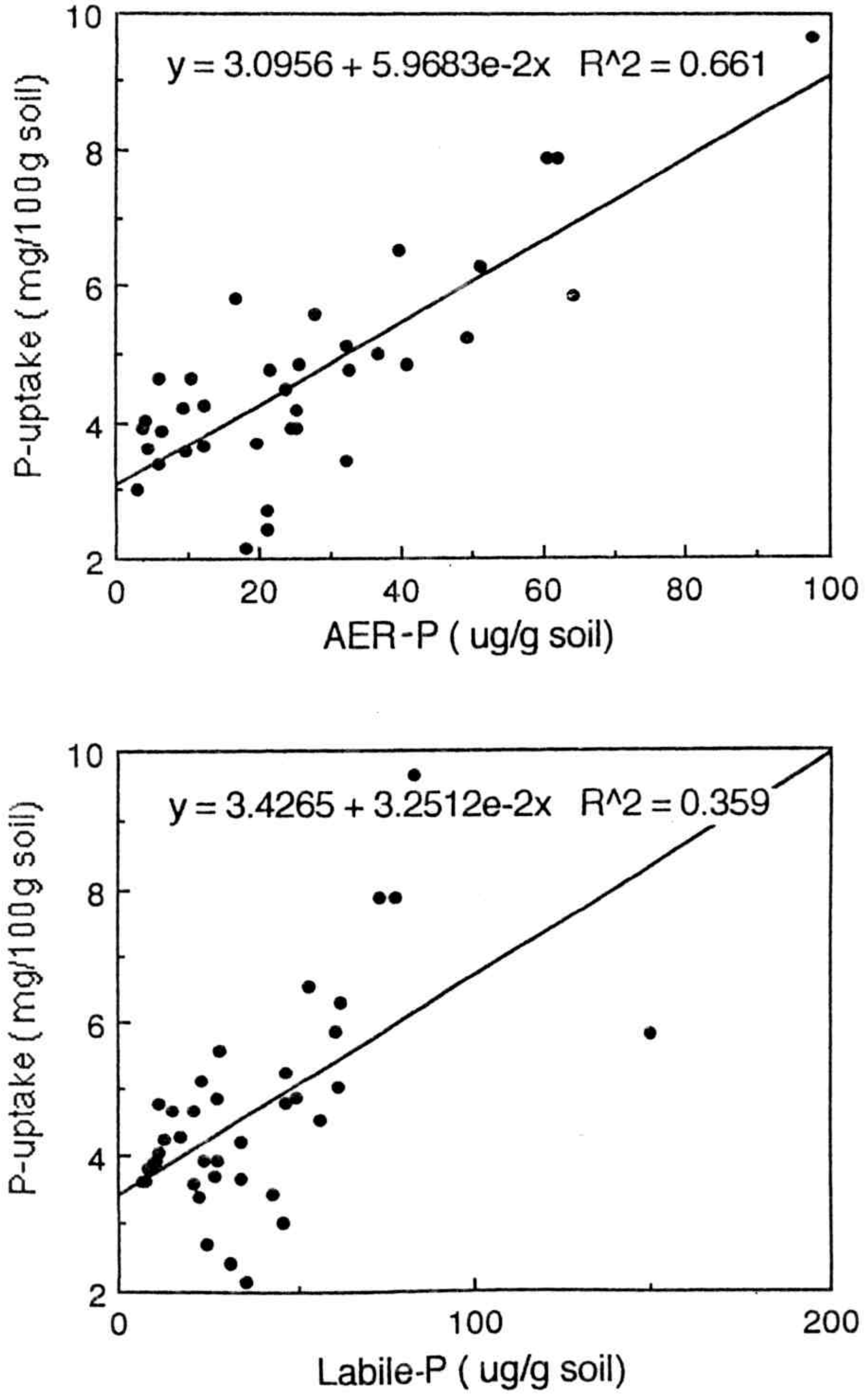


Fig. (7). The relationship between labile-P as well as AER-P ($\mu g/g$ soil) and P uptake by rye plants (mg/100 g soil).

A highly significant relationship was achieved between labile phosphorus extracted from the investigated soils by ^{32} P-exchange technique and P-uptake by the rye plants (r = 0.607).

With respect to the different categories of the soils, the "r" values obtained were 0.477 , 0.758 , 0.868 and 0.566 for the noncalcareous , calcareous , heavy textured and the light textured soils , respectively . These results may confirm the suitability of ^{32}P-exchange technique as a means for predicting the P-uptake in the different soils , particularly , the heavy textured and the calcareous ones .

The data presented in Table (3) show the values of phosphorus extracted by Dowex AG Type 1 X 8 mesh 20-25 , Cl^{-} form anion resin . The obtained figures ranged from 3.1 to 137.8 ppm P with an average of 26.5 ppm . The AER-extractable P averaged 37.2 , 20.1 , 40.7 and 21.6 ppm in the noncalcareous , calcareous, heavy textured and light textured soils , respectively .

Statistical analysis shows, generally, a high significant relationship between AER-extractable P from the investigated soils, as a whole, and P-uptake by the rye plants (r = 0.803) . It is worthy to mention that such a relation was also highly significant between P-uptake by plants and AER-extractable P in the noncalcareous soils (r = 0.68) , the calcareous soils (r = 0.865), the heavy textured soils (r = 0.934) and the light textured soils (r = 0.634) .

The obtained results clearly indicate that the anion exchange resin is a quite reliable means for assessing the availability of soil phosphorus in alkaline soils , particularly the heavy textured and the calcareous ones .

It is worthy to refer that the AER method showed a trend almost similar to that obtained with ^{32}P-exchange technique , moreover, the relation was more tighed in case of AER . These results are in accordance with many investigators such as Abd El-Aal (1975) , Abbas (1980) and Bowman et al. (1978) who found a high significant relationship between P-uptake and available phosphorus extracted by each of the AER and ^{32}P-exchange technique.

It was mentioned that AER extracts all or mostly all of the isotopically exchangeable labile P pool. Wolf et al. (1986) demonstrated that, in soils with a high fixation capacity , the isotopic exchange technique should not be used to measure labile phosphorus . Instead, the AER should be employed. Naidu et al., (1991) obtained a close relationship between AER -extractable P and P-uptake, while the relationship between isotopically-exchangeable P and P-uptake was very poor. They attributed the superiority of the resin method over many other methods in predicting plant P uptake to two reasons. Firstly, a weak anion-exchange resin such as Cl^- resin, does not alter the surface properties of the soils as the other reagents do. Secondly, the large and continuous P sink provided by the Cl^- resin makes it acts rather like a plant root with a very high capacity for phosphorus absorption. Also, the pH of the soil suspensions during the extraction is close to that of the soil and thus in a pH range comparable to that in the field.

Le Mare (1981) indicated that exchangeable P measured by exchange of ^{31}P with ^{32}P is too-expensive and laborious for extensive soil testing.

Data shown in Table (5) reveal that, AER-extractable P was significantly correlated with soil organic matter (r =0.644) , clay content (r = 0.480) , Al-ox (r = 0.375) and surface area (r = 0.428) but negatively correlated with soil pH (r=-0.517).

Labile P showed high significant correlations with OM (r = 0.604) , Fe-ox (r = 0.508) , Al-ox (r = 0.458) , surface area (r = 0.449) as well as with clay content (r = 0.339) and also a significant but negative correlation with soil pH (r = -0.390).

4.2. Assessment of soil P availability using parameters composited from the simple ones:

Conclusions based on simple correlations between soil available phosphorus extracted by chemical methods and plant P uptake may be of limited value. It is therefore important to determine, through multiple regression analysis, the relationship between plant P uptake and the various parameters of soil phosphorus availability. Such multiple regression makes it possible to see which of the extractant nearly duplicates the behavior of the plant in the field in its extraction pattern of phosphorus.

Stepwise regression analysis is considered by Draper and Smith (1966) to be the best of the variable selection regression models. The stepwise regression procedure re-evaluates each independent variable in a regression when a new variable is added.

Stepwise regression analysis for the data given in Tables (3, 7 and 12) was conducted and the results obtained were summarized in Table (6). In the calculation of the regression analysis, data of the various parameters of soil P availability are taken as the independent factor and plant P uptake as the dependent one.

Data in Table (6) clearly show that, the Colwell method, generally, could be considered as the most reliable method for assessing soil P availability where a high significant relationship with plant P uptake was achieved ($r = 0.830$) . The contribution of this method to the plant P uptake was about 70%. This relation could be represented by the following equation derived from the regression analysis :

$$\textbf{P-uptake} = 3.070 + 0.033\ \textbf{Colwell-P}.$$

The correlation was improved by introducing the water-soluble P fraction extracted at 1:5 soil-water ratio as a new variable in a combination with the Colwell-extractable P where the R^2 value became 0.741 and the relation was represented by the equation:

$$\textbf{P-uptake} = 3.186 + 0.433\ H_2O - P\ (1:5) + 0.021\ \textbf{Colwell-P}$$

When Sr-citrate-extractable P fraction was introduced besides distilled water extractable P (at soil-water ratio 1:5) and Colwell-extractable P in a composited relations, the correlation with P-uptake became more pronounced, and the value of R^2 raised up to 0.778 . The composited relation was then represented by the equation:

Table (6): *Simple and multiple correlation coefficients between various soil P parameters and P uptake by rye plants.*

Tested soils	factors correlated	correlation coefficients	
		r	R
All tested soils	P-uptake vs. Colwell-P	*** 0.835	-
	P-uptake vs. H_2O-P (1:5)+Colwell-P	-	0.861
	P-uptake vs. H_2O-P (1:5)+Sr-citrate-P + Colwell-P	-	0.882
	P-uptake vs. H_2O-P (1:5) Citrate-P + Colwell-P + Org. P	-	0.912
Non-calcareous soils (<7% $CaCO_3$)	P-uptake vs. Sr-citrate-P	*** 0.710	-
Calcareous soils (>7% $CaCO_3$)	P-uptake vs. Colwell-P	*** 0.926	-
Soils containing >40% clay	P-uptake vs. AER-P	*** 0.934	-
Soils containing <40% clay	P-uptake vs. H_2O-P (1:5)	*** 0.713	-
	P-uptake vs. $CaCl_2$-P+H_2O-P (1:5)	-	0.816

*Where ***= significant at 0.001.*

P-uptake = 2.879 + 0.405 H_2O-P (1:5) + 0.026 Sr-citrate-P + 0.018 Colwell-P.

The stepwise regression achieved the highest degree of correlation ($R^2 = 0.831$) by introducing the organic P in combination with the aforementioned extractable forms of P and the relation was represented by the equation:

P-uptake = 2.880 + 0.296 H_2O-P (1:5) + 0.060 Sr-citrate-P + 0.023 Colwell-P + 0.007 organic-P

On the other hand, the relationship between the P-uptake by plants and P extracted by the different methods from the investigated soils in each of the studied categories did not, generally, improve when these variables were analyzed by the stepwise regression analysis.

However, in the category of the light textured soils, introducing the $CaCl_2$-extractable P fraction with the water soluble P fraction extracted at the 1:5 soil-water ratio improved the correlation with p-uptake. The R^2 raised from 0.508 to 0.666, and the relation was represented by this equation:

P-uptake = 3.706 + 0.213 $CaCl_2$-P + 0.481 H_2O-P(1:5).

4.3. *Availability of soil phosphate fractions for plant utilization:*

Soil phosphorus is composed of organic and inorganic forms. The inorganic P fractions is further subdivided into aluminum, iron and calcium phosphates. The abundance of these forms is a function of soil pH rather than any other soil factor.

Chang and Jackson (1957) fractionated the soil inorganic phosphorus into calcium, iron, aluminum and occluded phosphates through a method based on sequential extraction steps. The Chang and Jackson fractionation procedure was subjected to many modifications. One of these modifications is that of Olsen and Sommers (1982) which involves sequential extraction of Al, Fe-P fraction with 0.1 M NaOH; occluded-P fraction with citrate-dithionate-bicarbonate, and Ca-P fraction with 1 M HCl.

This part of work was undertaken to investigate; (a) the relative abundance of the inorganic P fractions; Fe, Al-P, occluded-P and Ca-P, in the different soils of Egypt; (b) the relations of these P fractions with the different soil properties (c) the relations of P fractions with values of available P extracted by the different extractants or taken up by rye plants.

Data obtained for the various inorganic P fractions are presented in Table (7). These results show that, although these P fractions varied widely within the investigated soils, yet their relative abundance in most of these soils is in the following descending order; **Ca-P > Occluded-P > Fe, Al-P**

The dominancy of Ca-P fraction and the low abundance of Fe, Al-P represent a general trend in alkaline soils where the soil pH induces the formation of sparingly soluble apatite like minerals which comprise the main source of P and, at the same time, adverse the tendency of iron and aluminum phosphate formation, Chang and Jackson (1958).

The abundance of calcium-P, occluded-P and iron+aluminum-P, in all the tested soils categories, generally, amounted to 96.4, 2.1 and 1.5 % of the total content of inorganic soil phosphate, respectively.

Comparable results were obtained with both alluvial and calcareous soils of Egypt by El-Rashidi (1972) and Amer and Abou-El-Roos (1975).

Data presented in Table (7) also indicate that the sum of the different phosphate fractions is less than the total amount of soil inorganic P in the same samples. This trend can be attributed to the random error, particularly if we remember that Williams et al. (1967) have reported random errors as high as 20-30 ppm.

Taha (1975) obtained somewhat different figures for the properties of Al-P, Fe-P, occluded-P and Ca-P, ranging from 8.7 to 15.8%, 0.82 to 1.3% and 10.0 to 13.7%, respectively of the total inorganic P contained in surface samples of Egyptian soils.

4.3.1 Fe,Al-P fraction in soils:

4.3.1.1. Occurrence in soils:

The Al-P fraction includes phosphorus of the fine crystals of minerals such as variscite, tarankite and wavellite, which may exist as solids in soil solution, or aluminum phosphate precipitated on alumino-silicates or gibbsite, while Fe-P fraction includes phosphorus fine crystals of natural minerals such as strengite and dufrenite in soil solutions, or the precipitated

Table (7): Soil contents of various phosphorus fractions in ugp/g soil.

Soil No.	Soil location	Total-P	Inorg-P	Org-P	Fe.Al-P	Occlud. P	Ca-P	Sum of extracted inorganic P fractions
(1) Heavy textured soils:								
(a) Calcareous soils:								
1	Ebees	966	685	180	11.4	5.4	570.5	577.2
2	Kafer El-Dawar	697	368	196	6.3	3.4	455.6	465.3
3	Housh Essa	1036	873	94	10.4	2.9	721.8	735.1
4	El-Amerya (A)	717	479	158	23.9	93.9	258.1	375.9
(b) Non-Calcareous soils:								
5	Moshtohor	1455	1181	239	10.4	2.2	1036.3	1048.9
6	Fayoum	1574	1344	265	11.2	25.9	1116.9	1153.9
7	El-Hamoul	957	734	96	5.7	71.3	524.2	601.1
8	Shalma	877	727	83	5.6	11.7	472.6	489.9
9	Menia El-Kamh	1315	1038	285	5.7	12.7	814.5	832.9
10	Meet-Gamr	1176	988	193	5.5	6.3	354.0	365.9
11	Etay El-Baroud	877	704	115	7.3	10.3	512.6	530.2
12	Tanta	1196	900	175	12.0	15.1	592.7	619.9
13	Kafer El-Zayat	1315	1058	183	8.5	9.3	701.6	719.4
14	Damanhour	917	690	169	5.9	2.4	520.2	528.5
(2) Light textured soils:								
(a) Calcareous soils:								
15	Ganaklies (B)	180	167	9	10.4	1.5	124.9	136.9
16	El-Amerya (B)	578	417	110	15.9	79.1	214.5	309.5
17	Burg El-Arab (A)	498	343	75	8.7	4.4	306.4	319.6
18	Burg El-Arab (B)	638	395	110	1.1	2.9	508.1	512.1
19	West Noubaria (A)	239	132	44	3.0	2.4	65.9	71.3
20	West Noubaria (B)	359	272	26	0.6	0.5	282.3	283.3
21	East Noubaria	159	136	40	6.6	4.4	90.0	101.1
22	El-Henwa	558	427	32	7.6	2.9	455.6	466.2
23	El-Mazraa	997	826	47	3.0	1.9	858.9	863.9
24	El-Satah	359	262	2	4.7	2.4	270.2	277.3
25	Wadi Sidr	558	373	22	5.7	1.9	520.2	527.8
26	Wadi Sidri	877	681	31	1.5	2.9	802.4	806.9
27	Wadi Arab El-Soghier	1674	1098	22	2.3	8.8	1512.1	1523.2
28	Wadi El-Awag	857	615	66	2.1	3.3	563.5	568.9
29	Wadi Mehash	598	474	9	2.8	4.9	540.3	548.0
30	Wadi Abu-Gerf	877	558	13	2.0	5.6	476.3	483.9
(b) Non-Calcareous soils:								
31	Meet-Kenana (A)	439	272	25	17.7	2.4	213.7	233.8
32	Meet-Kenana (B)	259	109	57	4.7	2.9	86.7	94.4
33	El-Dair	917	765	208	4.0	4.4	548.4	556.8
34	Benha (A)	1335	771	228	4.6	3.4	570.5	568.5
35	Benha (B)	1036	973	272	56.9	9.8	741.9	808.7
36	Quesna	937	799	182	8.9	12.9	645.2	667.0
37	Giza	1315	1111	202	4.4	6.8	959.7	970.9
38	Kom Ambo	578	461	0	4.7	7.3	559.1	571.1
39	Ganaklies (A)	518	404	92	12.3	1.0	362.9	376.2

phosphates on iron oxides surfaces, Chang and Jackson (1957).

Accordingly, the P fractionation procedure developed by these investigators involved the extraction of the Al and Fe fractions of soil P separately. However, owing to the great similarity of these two P fractions, Olsen and Sommers (1982) procedure was based on the extraction of both fractions in one step using 0.1 M NaOH.

Data obtained reveal that the abundance of Fe, Al-P fraction in soils differs widely from one soil category to another and from one soil sample to another showing a wide range of 0.6 to 56.9 ppm with a general average of 8.4 ppm .

The mean values of the Fe,Al-P fraction in the noncalcareous , calcareous, heavy textured and light textured soils are 10.3, 6.5, 9.3 and 7.8 ppm, respectively. The relatively low abundance of this fraction in the investigated soils could be explained on a basis of pH effect, as their formation is favoured mainly under acidic conditions and in soils containing high amounts of free iron oxides. Such features are not dominant in the alkaline soils, under investigations, Ahmed and Jones (1967).

The results may also suggest a relatively higher Fe, Al-P content in both noncalcareous and heavy textured soils. The light textured as well as the $CaCO_3$ in soils may inversely affect the soil content of Fe, Al-P fraction. In this respect, El-Rashidi (1972) found that the calcareous soil of Egypt are almost free from the iron P fraction. On the other hand, Taha (1975) found that the cultivated alluvial soils of Egypt contain high amounts of aluminium P fraction (ranging from 34 to 50 ppm).

4.2.1.2. *Fe, Al-P fraction in relation to plant P-uptake and soil P availability:*

Values of simple correlation coefficient between the Fe, Al-P fraction from one hand and available phosphorus extracted by different methods as well as P uptake by rye plants from the other one are presented in Table (8) and illustrated in Figs. (8, 9 and 10).

Regarding the soil P fractions as related to plant P uptake, it is well established that plant P uptake serves as a reference for evaluating the accuracy of the methods of P availability determination and various inorganic phosphate forms or fractions extracted.

In the current work, P-uptake was evaluated using rye plants growing under greenhouse conditions for 25 days. The obtained data, generally, show a high significant relationship between Fe, Al-P fraction and P-uptake by rye plants (r = 0.438) which agrees with Khera and Datta (1969) and Ibrahim et al. (1980).

Chang and Chu (1961) attributed the high availability of Fe, Al-P fractions to their surface activity which is greater than those of the other forms of inorganic phosphate.

With respect to the different soils used in this study, the results obtained indicate that, except to the noncalcareous soils, the abundance of Fe, Al-P fraction in soil correlated significantly with P taken up by rye plants in calcareous, heavy

Table (8): Values of simple correlation coefficient of soil P fractions with different methods of soil P extraction and P-uptake by rye plants.

Tested soils	P fraction						Soil P test						
		P-uptake (rye)	Olsen P	AER P	Bray1 P	Bray2 P	Labile P	$CaCl_2$ P	H_2O-P (1:5)	H_2O-P (1:60)	H_2O-P (1:250)	Sr-citr. P	Colwell P
All the tested soils	Fe , Al-P	0.438**	0.340*	0.320*	0.142	0.063	0.818***	0.847***	0.365*	0.920***	0.911***	0.290	0.505**
	Occlud. P	0.504**	0.779***	0.636***	-0.086	-0.095	0.411*	0.509**	0.622***	0.287	0.392*	0.095	0.729***
	Ca-P	0.221	-0.023	0.109	-0.002	0.292	0.300	0.077	-0.007	0.170	0.061	0.466**	0.107
Non-calcareous Soils (<7% $CaCO_3$)	Fe , Al-P	0.290	-0.042	-0.112	0.035	-0.202	0.830***	0.946***	0.068	0.939***	0.932***	0.196	0.393
	Occlud. P	0.029	0.248	0.043	-0.254	-0.158	0.188	-0.047	-0.199	-0.088	0.025	0.156	0.307
	Ca-P	0.620**	0.495*	0.509*	-0.229	0.416	0.483*	0.331	0.263	0.384	0.210	0.795***	0.734***
Calcareous soils (>7% $CaCO_3$)	Fe & Al-P	0.751***	0.897***	0.916***	0.463*	-0.067	0.858***	0.837***	0.861***	0.897***	0.859***	0.535*	0.877***
	Occlud. P	0.769***	0.912***	0.867***	0.709***	-0.215	0.770***	0.837***	0.945***	0.847***	0.834***	0.298	0.867***
	Ca-P	-0.124	-0.197	-0.150	-0.006	0.125	-0.020	-0.169	-0.206	-0.286	-0.214	0.042	-0.204
Heavy textured soils (containing >40% clay)	Fe , Al-P	0.762**	0.875***	0.859***	0.022	-0.293	0.612*	0.925***	0.897***	0.758***	0.751***	0.000	0.885***
	Occlud. p	0.385	0.607*	0.385	-0.286	-0.456	0.296	0.568*	0.484	0.186	0.433	-0.190	0.599*
	Ca-P	-0.389	-0.075	0.195	0.514	0.733***	0.443	-0.097	-0.009	0.305	0.000	0.822***	0.040
Light textured soils (containing <40% clay)	Fe Al-P	0.517**	0.238	0.250	0.162	0.147	0.932***	0.966***	0.247	0.966***	0.957***	0.466*	0.629***
	Occlud. P	0.420*	0.864***	0.754***	-0.064	-0.123	0.327	0.240	0.599***	0.239	0.293	-0.003	0.723***
	Ca-P	-0.046	-0.156	-0.103	-0.161	0.075	0.215	0.090	-0.087	0.075	-0.004	0.269	-0.014

*Where *, **, *** significant at 0.05, 0.01 and 0.001, respectivily.*

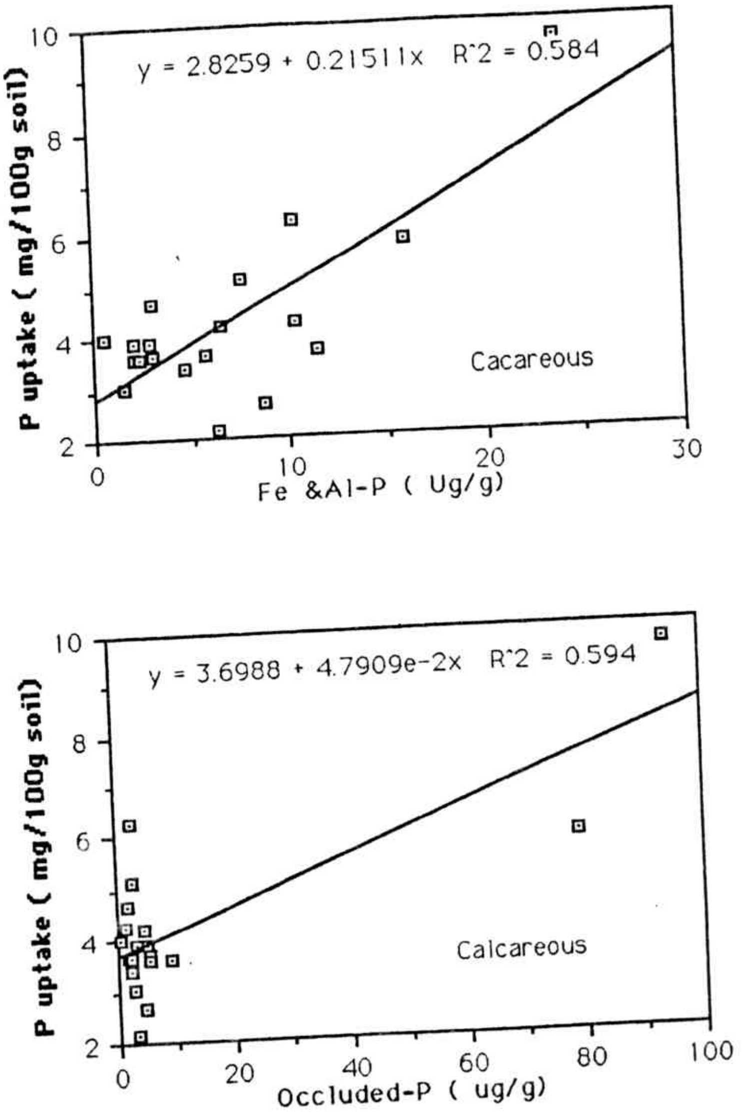
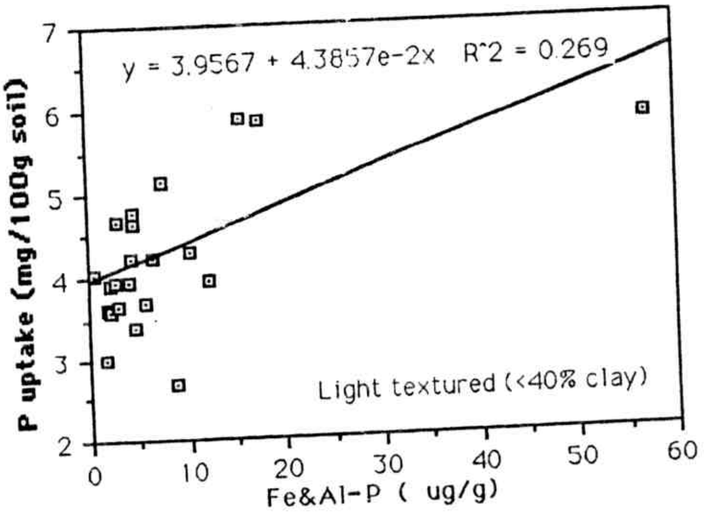


Fig. (8). The relationship between Fe, Al-P as well as occluded-P (µg/g) in calcareous soils and P uptake by rye plants (mg/100 g soil).



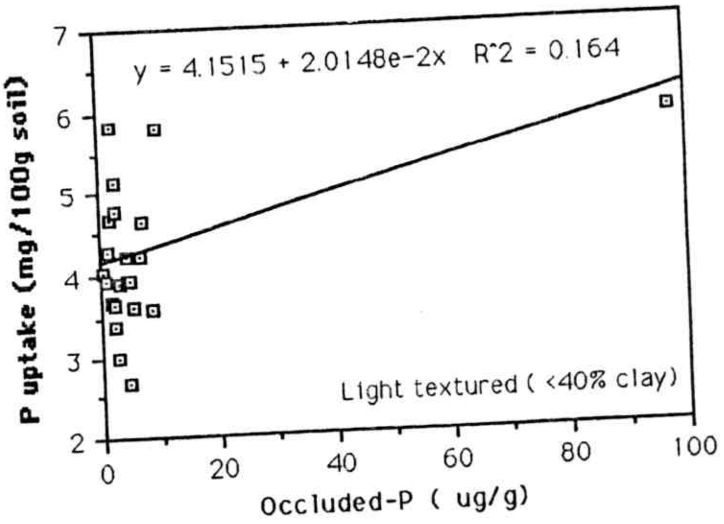


Fig. (9). The relationship between Fe, Al-P as well as occluded-P (µg/g) in light textured soils and P uptake by rye plants (mg/100 g soil).

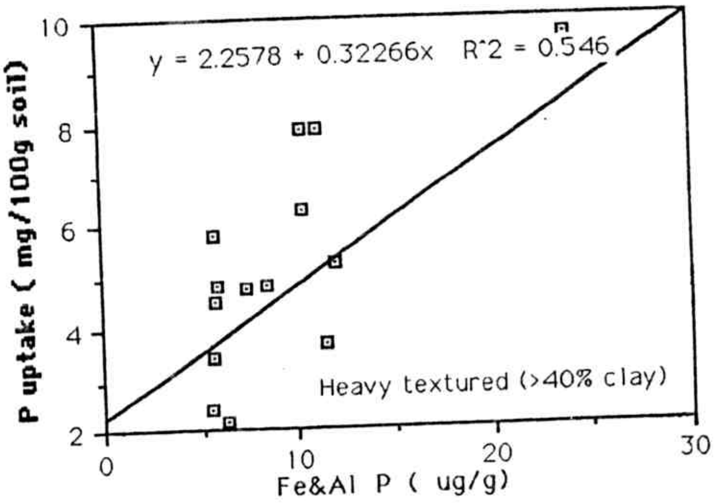


Fig. (10). The relationship between Fe, Al-P (µg/g) in heavy textured soils and P uptake by rye plants (mg/100 g soil).

textured and light textured soils with "r" values of 0.751, 0.762 and 0.517, respectively. These findings are in harmony with those obtained by Taha (1975) who emphasized the importance of Al-P as the main source of phosphorus taken up by plants in alluvial soils, and Singh et al. (1966) who mentioned that the Fe-P fraction supplies high amounts of phosphorus to plants on almost neutral soils containing large amounts of this fraction.

Regarding the relationship between Fe, Al-P fraction and available P extracted chemically through the used methods, data obtained, generally, show a close relationship between Fe, Al-P fraction and water-soluble P extracted at wide ratios (1:60 and 1:250). The correlation coefficient values were 0.920 and 0.911, respectively. In case of the narrow ratio (1:5), the relationship was only significant at 5% level of significancy (r = 0.365).

A highly significant relationship was also determined between available soil P as extracted by $CaCl_2$ and ^{32}P- exchange technique and the Fe, Al-P fraction with "r" values of 0.847 and 0.818, respectively. On the other hand, no significant relationship between Fe, Al-P fraction and soil P extracted by Bray-1, Bray-2 and Sr-citrate procedures could be achieved.

Regarding the relationships in the different soil categories, data show a close relationship between the level of Fe, Al-P fraction in soils and the values of soil P extracted by 0.01 M $CaCl_2$ solution in all the four tested soil categories. The mean "r" values determined for this relation are 0.946, 0.837, 0.925 and 0.966 in noncalcareous, calcareous, heavy textured and light textured soils, respectively. It is clear that the 0.01 M $CaCl_2$ solution extracted amounts of soil P which are very much related to the abundance of Fe, Al-P fraction in the alkaline soils.

Distilled water, especially at wide ratios (1:60 and 1:250), also extracted soil P amounts that are highly significantly correlated with Fe, Al-P fraction in soils. The relation being very close in the light textured as well as in the noncalcareous soils. The "r" values obtained are 0.966 and 0.957, for 1:60 and 1:250 soil : water ratios, respectively in the light textured soils and the corresponding values in the noncalcerous soils are 0.939 and 0.932, respectively. These results may suggest a relative importance due to Fe, Al-P fraction as a source of P supply to soil solution.

Also, a very highly significant relationship existed between Fe, Al-P and P extracted through ^{32}P- exchange technique in light textured (r = 0.932), calcareous (r = 0.858) and noncalcareous (r = 0.830) soils. In the heavy textured soils, the relationship was only significant at 5% level of significancy (r = 0.612).

Available P values extracted according to Olsen as well as Colwell methods are related significantly to the level of Fe, Al-P in both calcareous and heavy textured soils, with "r" values of 0.897 and 0.875, for Olsen method in the two soil categories, respectively The corresponding values for Colwell in the same soils are 0.877 and 0.885, respectively.

Hooker et al. (1980) indicated that $NaHCO_3$-extractable P

(Olsen-P) correlated well with Fe, Al-P fraction and attributed this relation to the higher specific surface activity of this fraction at high pH levels and its greater solubility as compared to other forms of inorganic P.

4.3.1.3. Fe, Al-P fraction in relation to soil characteristics:

Concerning the relationship of Fe, Al-P abundance in the tested soils with different soil characteristics (Table 9), show following correlations:

Positive significant correlation with clay fraction in calcareous soils (r = 0.547), soil pH in noncalcareous soils (r = 0.511), organic matter content in both calcareous soils (r = 0.712) and the light textured soils (r = 0.476) and with Fe-ox abundance in light textured soils (r = 0.630). Halst~~e~~ad (1967) and Taha (1975) reported that the proportion of Al-P fraction tends to increase with increasing the clay fraction in soils.

The obtained data show also a negative and significant relations with respect to clay content in heavy textured soils (r = - 0.573), with pH in calcareous soils (r = -0.508) with Al-ox (r = - 0.784) as well as surface area (r = -0.662) in the heavy textured soils. Ahmed and Jones (1967) reported that the distribution and amounts of free Fe_2O_3 oxides, rather than pH or calcium saturation, seem to determine the relative abundance of the inorganic P fractions. For alkaline soils, they found that soils with high Fe_2O_3 content bonded most of its inorganic P as iron P, whereas soils with low Fe_2O_3 content bonded most of the P

Table (9): Values of simple correlation coefficient of phosphorus fractions with some soil characteristics.

Tested soils	P fraction	Clay	pH	OM	Fe-ox	Al-ox	Surface area
All the tested soils	Fe , Al-P	0.029	-0.076	0.349	0.255	0.054	0.026
	Occlud. P	0.252	-0.089	0.261	0.068	0.073	0.185
	Ca-P	0.110	-0.165	0.217	0.182	0.287	0.260
Non-calcareous Soils (<7% $CaCO_3$)	Fe , Al-P	-0.331	0.511*	0.127	0.183	-0.232	-0.289
	Occlud. P	0.282	0.080	-0.097	0.436	0.319	0.348
	Ca-P	0.105	-0.249	0.471*	0.171	0.406	0.370
Calcareous soils (>7% $CaCO_3$)	Fe , Al-P	0.547*	-0.508*	0.712**	0.272	0.317	0.422
	Occlud. P	0.305	-0.201	0.477*	-0.089	-0.026	0.190
	Ca-P	-0.016	0.016	-0.051	0.061	0.039	0.013
Heavy textured soils (containing >40% clay)	Fe , Al-P	-0.573*	0.376	0.452	-0.506	-0.784***	-0.662***
	Occlud. p	-0.159	0.619*	-0.006	0.058	-0.482	-0.240
	Ca-P	-0.284	-0.380	0.014	-0.042	0.380	0.262
Light textured soils (containing <40% clay)	Fe , Al-P	0.143	-0.109	0.476*	0.630***	0.246	0.136
	Occlud. P	0.530**	-0.110	0.491**	0.055	0.760	0.208
	Ca-P	0.050	-0.069	0.190	0.282	0.290	0.291

*Where *, **, *** significant at 0.05, 0.01 and 0.001, respectivily.*

as calcium and aluminum phosphate.

Morillo and Fassbender (1968) obtained a negative correlation ($r = -0.700$) between soil pH and Fe-P, and a positive correlation ($r = 0.769$) with Al-P .

Pirki and Novozamsky (1967) found that the pH at which the proportion of aluminum P began to increase sharply was 6.5 to 7.50 .

The contradictory results obtained for the abundance of Fe, Al-P fraction with clay content, Al-ox, Fe-ox and surface area of soils could be attributed to the different properties inherted from the parent material of the tested soils. However, the relation with the soil pH which was positive in noncalcareous soils, and negative in the calcareous ones still interesting and needs a more resonible explanation. Such an explanation might be that soil pH which is the controlling factor of the different reactions involved in the soil systems affects the noncalcareous soils in a manner completely different from the calcareous ones. Hence the net abundance of such fraction was quite different in two soil categories.

The positive relation with organic matter content in calcareous and light textured soils may give a further importance to the inducing effect due to organic matter content on the abundance of Fe, Al-P fraction in both calcareous and light textured soils.

Concerning the previous investigations dealing with such problems, El-Rashidi (1972) obtained a positive relation between soil content of Al-P and content of the clay fraction in soils.

4.3.2. *Occluded P fraction in soils:*

4.3.2.1. *Occurence in soils:*

This form of soil P includes two P fractions, i.e., the reductant soluble Fe-P, and occluded Al-P. Both P fractions could be coated by iron oxides. This form of iron phosphate can only be dissolved after removal of the iron oxide films by the dithionite-citrate reduction treatment. Thus, the term " reductant Fe-P" refers to the part of Fe-P extracted by dithionite treatment. The dithionite treatment dissolves iron phosphate, but not aluminum phosphate, coated also by iron oxides. Therefore this occluded Al-P fraction is removed by using the NaOH solution after the extraction of the " reductant Fe-P " . It is worthy to mention that Olsen and Sommers (1982) extracted the occluded P fraction using citrate-dithionite-bicarbonate treatment.

Results obtained for occluded P fraction (Table 8) show that the occurrence of this P fraction in alkaline soils comes after Ca-P and before Fe, Al-P fraction, ranging from 0.5 to 93.9 ppm with an average of 11.6 ppm P. The mean values in the tested soils are, 11.5 , 11.8 , 16.0 and 7.22 ppm for noncalcareous , calcareous , heavy textured and light textured soils , respectively. It is obvious that the variation through amounts of this fraction are not wide, however, the highest content of occluded P exhibited in the heavy textured soils and the least in the light textured ones.

The relatively high values of occluded P, as compared to the Fe, Al-P fraction in the tested soils, may be due to its resistance to weathering and subsequent accumulation in the soils. Chang and Jackson (1958) reported that the sequence of weathering and transformation of P species corresponds with the solubility product principle and are of the order Ca-P > Al-P > Fe-P > occluded-P

Amer and Abou El-Roos (1975) concluded that the proportion of this fraction appears to be an inherted property of the parent material of the Nile alluvial soils i.e., Nile mud.

4.3.2.2. Occluded P in relation to plant P-uptake and soil P availability:

Results obtained (Table 8, and Figures 8,9 and 10) show a highly significant relationship between the average content of the occluded-P of the tested soil categories and P-uptake by rye plants (r=0.504).

With respect to the different soil categories, results indicate also a very highly significant relationship with P-uptake in calcareous soils (r = 0.769). The corresponding value in light textured soils was 0.420.

In this respect, no significant relationship either in the noncalcareous nor in the heavy textured soils could be detected.

Taha (1975) concluded that occluded-P forms constitute a large proportion of inorganic P in alkaline soils, but appeared to be unavailable to plants, since the iron oxide coatings would have to be removed before the P release from coated P compounds.

Regarding the relation with soil P availability, data show that occluded-P fraction in the tested soils significantly correlated with the P values extracted following methods; Olsen, Colwell, AER, H_2O (1:5), $CaCl_2$, ^{32}P-exchange technique and H_2O (1:250) with corresponding "r" values 0.779, 0.729, 0.636, 0.622, 0.509, 0.411 and 0.392, respectively.

Accordingly, it may be concluded that occluded P fraction in alkaline soil could be extracted with fair accuracy, using the methods of Olsen, Colwell, AER and H_2O (1:5).

Regarding the different soil categories used in this study, data obtained show that occluded-P is significantly correlated with available P extracted by Olsen method in calcareous, heavy textured and light textured soils with "r" values of 0.912, 0.607 and 0.864, respectively. The corresponding values for Colwell method are 0.867, 0.599 and 0.723, respectively.

Noteworthy referring that distilled water, particulary at the least soil : water ratio (1:5), was very effective in predicting the availability of occluded-P in the calcareous soils, where "r" values were; 0.945, 0.847 and 0.834 for the ratios 1:5, 1:60 and 1:250 , respectively. The AER method was also very effective in predicting the availability of occluded-P in calcareous soils (r = 0.867) as well as in the light textured ones (r = 0.754).

are the least soluble.

The mean values obtained for this P fraction in noncalcareous, calcareous, heavy textured and light textured soils are 596, 480, 618 and 491 ppm, respectively.

4.3.3.2. *Calcium P fraction in relation to plant P-uptake and soil P availability:*

The results indicate that the relation between this fraction and P-uptake by rye plants in noncalcareous soils was highly significant (r = 0.620) but it was insignificant in the other soil categories. These results may suggest more important due to the Ca-P fraction in noncalcareous soils as a source of soil available P.

Concerning the relationship of this fraction with available P in soils, it is clear that Colwell and Sr-citrate methods are the most suitable methods for predicting the abundance of the Ca-P fraction in noncalcareous soils where highly significant correlations between these two variables were obtained, with "r" values of 0.734 for Colwell and 0.795 for Sr-citrate method.

Available P extracted by Olsen, AER, and ^{32}P exchange technique also significantly correlated with the occurrence of Ca-P fraction in noncalcareous soils, showing "r" values of 0.495, 0.509 and 0.483, respectively. The obtained data show that the Ca-P fraction could be considered as the most important fraction controlling the available P extracted by Colwell, Sr-citrate,

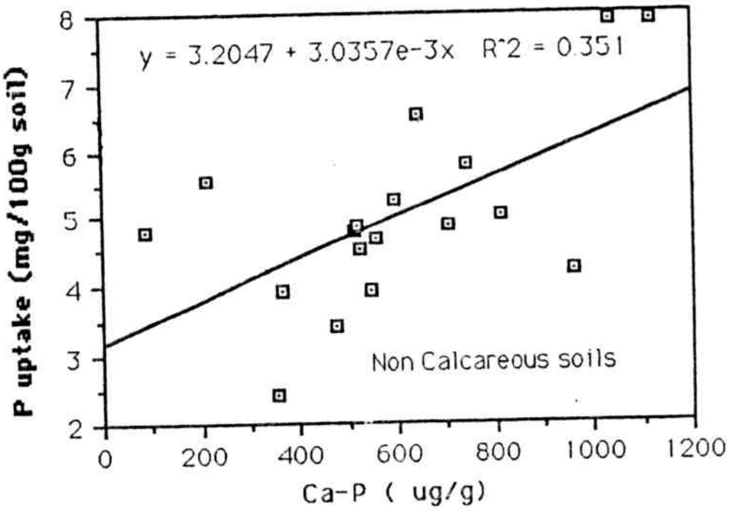


Fig. (11). The relationship between Ca-P (μg/g) in noncalcareous soils and P uptake by rye plants (mg/100 g soil).

Olsen, AER and ^{32}P exchange technique methods in the noncalcareous soils.

Also, a highly significant relationship in the heavy textured soils between abundant Ca-P fraction and available P extracted by both Sr-citrate and Bray-2 methods was obtained. The corresponding "r' values are 0.822 and 0.733, respectively. This trend is in accordance with that obtained by Taylor and Woods (1981) who indicated that available P extracted by Olsen and Bray-1 methods was positively correlated with Ca-P fraction.

However, no significant relationship could be observed between these two variables neither in the calcareous nor in the light textured soils.

4.3.3.3. *Ca-P fraction in relation to soil characteristics:*

Data in Table (9) show no significant relationship between Ca-P and each of the different soil characteristics tested, except with organic matter in the noncalcareous soils ($r = 0.471$).

4.4. *Assessment of soil P availability depending on P adsorption parameters.*

To investigate the reliability of the parameters related to P adsorption relations for assessing P availability in the alkaline Egyptian soils of widely varying physical and chemical properties, two isotherms namely; Langmuir as adopted by Olsen and Watanabe (1957) and Van Huay (1975) as described by Pagel and Van

Huay (1976) were tested.

The data presented in Tables (10 and 11) and Figs. (12 ,13, 14 and 15) reveal that the amounts of P sorbed by soils increased by increasing P concentration in the equilibrium solution. Such results are in accordance with those of Abd El-Aal (1975) and Abbas (1980).

4.4.1. *P adsorption parameters calculated according to the equation of Van Huay (1975):*

4.4.1.1. *Maximum P adsorption (P max.):*

As it was mentioned before, the maximum P adsorption (P max.) obtained from the Van Huay isotherm (1975) was considered as the amount of P sorbed upon application of P to the soil at the rate of 200 mg P/kg soil as proposed by Pagel and Van Huay (1976).

The values obtained for this parameter (Table 13) ranged from 36 to 185 mg p/kg with a general average of 127 mg p/kg soil. It could be noticed that the highest value was that of "Ebess" which is "highly calcareous and heavy textured soil", whereas the lowest one was that of "Meet-Kenanna (B)", which is a "noncalcareous and light textured soil". Accordingly, the results will be discussed in relation to these two factors and they may throw some light on the role played by each of the $CaCO_3$ and clay content in increasing the ability of soils to adsorb or retain phosphorus. This conclusion might be confirmed by the results of Loganathan et al. (1987) and Lajtha and Bloomer (1988) besides the correlation coefficient values which relate the maximum P adsorption

Table (10): Data for plotting adsorption isotherm after Pagel and Van Huay (1976)

No.	Soil type	Sorption parameter	Initial P concentration (mg/l)						
			0	0.5	2.5	5.0	10.0	15.0	20.0
1	Etay El-Baroud	I	0.20	0.25	0.51	0.82	1.90	3.39	5.12
		Q	-2.01	2.49	19.89	41.73	80.96	116.05	148.77
2	El-satah	I	0.01	0.05	0.66	1.74	4.95	8.93	12.98
		Q	-0.10	4.48	18.38	32.55	50.44	60.64	70.13
3	Wadi El-Awage	I	0.01	0.16	1.16	2.80	6.32	10.84	13.46
		Q	-0.10	3.33	13.35	21.95	36.72	41.58	65.37
4	Wadi Abu-Garf	I	0.00	0.15	1.07	2.86	6.32	10.40	14.29
		Q	0.00	3.44	14.25	21.37	36.72	45.99	57.03
5	El-Ameria (B)	I	0.26	0.35	0.69	0.96	2.70	4.76	6.88
		Q	-2.61	1.42	18.09	40.39	72.99	102.34	131.14

I = intensity factor (mg P/l).
Q = Quantity factor (mg P/kg soil).

Table (11): Data for plotting adsorption isotherm after Pagel and Van Huay (1976).

No.	Soil type	Sorption parameter	Initial P concentration (mg/l)					
			0	2.5	5.0	7.5	10.0	20.0
1	Moshtohor	I	0.29	0.31	0.87	0.96	1.54	9.11
		Q	-2.95	21.93	41.31	65.40	84.61	108.85
2	Meet-Kenana (A)	I	0.28	1.13	2.79	4.14	5.81	14.26
		Q	-2.87	13.70	22.10	33.61	41.91	57.42
3	Meet-Kenana (B)	I	0.04	1.27	3.34	5.23	5.33	16.37
		Q	-0.43	12.29	16.62	22.73	46.72	36.32
4	El-Dair	I	0.05	0.20	0.68	0.90	2.06	6.07
		Q	-0.50	23.04	43.16	65.97	79.40	139.26
5	Benha (A)	I	0.07	0.19	0.77	0.91	1.73	5.11
		Q	-0.72	23.13	42.30	65.85	82.70	148.85
6	Benha (B)	I	0.90	0.83	2.12	2.19	2.97	6.70
		Q	-9.01	16.73	28.73	53.13	70.34	132.86
7	Quesna	I	0.30	0.40	1.17	1.47	2.47	3.49
		Q	-3.02	21 04	38.24	60.31	75.28	165.06
8	Giza	I	0.06	0.12	0.57	1.01	1.60	4.66
		Q	-0.64	-23.75	44.23	64.92	83.93	153.33
9	Fayoum	I	0.31	0.34	1.32	1.04	2.40	5.37
		Q	-3.14	21.63	36.74	64.59	75.90	146.29
10	El-Hamoul	I	0.07	0.08	0.87	0.58	0.91	2.94
		Q	-0.73	24.21	41.23	69.14	90.94	170.59
11	Shalma	I	0.04	0.05	0.19	0.35	0.51	2.36
		Q	-0.42	24.48	48.08	71.51	94.85	176.34
12	Menia El-Kamh	I	0.16	0.19	0.33	0.59	1.48	3.13
		Q	-1.65	23.08	42.72	69.08	85.17	168.67
13	Meet-Gamr	I	0.06	0.11	0.40	0.82	1.09	1.71
		Q	-0.64	23.90	45.94	66.78	89.08	162.92
14	Tanta	I	0.25	0.31	0.76	1.20	1.93	5.43
		Q	-2.51	21.89	42.41	63.05	80.64	145.65

Table (11): Cont.

			Initial P concentration (mg/l)					
No.	Soil type	Sorption parameter	0	2.5	5.0	7.5	10.0	20.0
15	Kafer El-Zayat	I	0.09	0.12	0.47	0.79	1.25	3.71
		Q	-0.93	23.82	45.30	67.11	87.44	162.92
16	Ebees	I	0.05	0.06	0.09	0.09	0.21	1.47
		Q	-0.49	24.39	49.07	74.12	97.94	185.30
17	Kafer El-Dawar	I	0.04	0.06	0.22	0.46	0.78	2.81
		Q	-0.43	24 38	47.76	70.40	92.17	171.87
18	Damanhour	I	0.05	0.11	0.38	0.74	1.07	3.52
		Q	-0.57	23.94	46.15	67.60	89.29	164.83
19	Housh Essa	I	0.28	0.43	0.82	1.25	2.14	5.43
		Q	-2.87	20.74	41.77	62.50	78.58	145.65
20	Kom Ambo	I	0.08	0.26	1.92	2.89	4.31	10.74
		Q	-0.79	22.40	30.82	46.09	56.87	92.58
21	Ganaklies (A)	I	0.09	-	2.04	-	4.90	11.12
		Q	-0.93	-	29.54	-	50.97	88.75
22	Ganaklies (B)	I	0.06	0.64	2.00	3.67	5.15	11.70
		Q	-0.57	18.60	26.97	38.32	48.50	82.99
23	El-Amerya (A)	I	0.97	0.77	2.45	1.89	4.75	7.54
		Q	-9.78	17.32	25.49	56.09	52.44	124.55
24	Burg El-Arab (A)	I	0.07	0.14	0.75	1.27	2.41	6.71
		Q	-0.72	23.63	42.43	62.28	75.84	132.86
25	Burg El-Arab (B)	I	0.05	0.12	0.48	0.93	1.70	5.69
		Q	-0.57	23.81	45.21	65.68	83.01	143.10
26	West Noubaria (A)	I	0.06	1.00	3.04	5.01	6.74	12.92
		Q	-0.57	15.02	19.63	24.84	32.64	70.84
27	West Noubaria (B)	I	0.06	0.31	1.05	1.78	2.68	3.41
		Q	-0.64	21 89	39.45	57.13	73.22	165.93
28	East Noubaria	I	0.06	0.78	2.24	4.19	5.31	12.02
		Q	-0.57	17.19	27.62	33.06	46.85	79.79

Table (11): Cont.

No.	Soil type	Sorption parameter	Initial P concentration (mg/l) 0	2.5	5.0	7.5	10.0	20.0
29	El-Henwa	I	0.12	0.42	1.26	2.51	3.71	10.48
		Q	-1.22	20.82	37.39	49.84	62.92	95.14
30	El-Mazraa	I	0.05	0.10	0.47	1.05	1.73	6.14
		Q	-0.50	23.91	45.30	64.48	82.70	138.62
31	Wadi Sidr	I	0.04	0.14	0.64	1.45	2.53	8.18
		Q	-0.43	23.63	43.59	60.53	74.66	118.16
32	Wadi Sidri	I	0.04	0.05	0.27	0.48	1.23	3.13
		Q	-0.40	24.48	47.33	70.18	87.73	168.67
33	Wadi Arab El-Soghier	I	0.05	0.48	1.55	3.01	4.54	8.50
		Q	-0.50	20.23	34.50	44.90	54.55	114.96
34	Wadi Mehash	I	0.04	0.62	2.09	3.52	6.14	9.33
		Q	-0.43	18.77	29.11	39.80	38.63	106.65

I = intensity factor (mg P/l).

Q = Quantity factor (mg P/kg soil).

Table (12): Some parameters of P adsorption calculated according to Van Huay and Langmuir isothers.

		Van Huay parameters								Langmuir parameters		
Soil No.	Soil location	P max.	PBC	EXP Desorp.	n	b	p-conc.	P-released (µg/g)	P-required (µg/g)	surface P	K_1X10^{-4}	K_2
	(1) Heavy textured soils:											
	(a) Calcareous soils:											
1	Ebees	185	53	0.49	161	-2	0.000	-70	124	21.9	1.79	22.67
2	Kafer El-Dawar	172	36	0.43	110	-8	0.005	-42	78	24.7	1.47	21.41
3	Housh Essa	146	26	2.87	78	-34	0.190	-1	27	39.8	0.64	27.39
4	El-Amerya (A)	125	19	9.78	57	-47	0.680	21	0	42.3	-	-
	(b) Non-Calcareous soils:											
5	Moshtohor	109	12	2.95	37	0	0.046	-25	37	42.9	2.56	12.40
6	Fayoum	146	25	3.14	76	-33	0.188	-1	26	43.1	0.85	23.40
7	El-Hamoul	171	35	0.73	107	-22	0.042	-26	61	48.7	1.78	27.10
8	Shalma	176	41	0.42	124	-7	0.003	-49	90	35.5	1.53	22.22
9	Menia El-Kamh	169	36	1.65	109	-29	0.071	-20	56	48.0	1.66	24.93
10	Meet-Gamr	163	31	0.64	93	-14	0.023	-28	59	18.1	1.76	12.57
11	Etay El-Baroud	149	27	2.01	82	-32	0.152	-5	32	28.4	0.39	38.46
12	Tanta	146	25	2.51	76	-27	0.126	-7	32	39.9	0.87	23.98
13	Kafer El-Zayat	163	31	0.93	95	-19	0.040	-24	55	33.7	1.86	22.88
14	Damanhour	165	32	0.57	96	-14	0.021	-29	61	16.4	2.22	22.42
	(1) Light textured soils:											
	(a) Calcareous soils:											
15	Ganaklies (B)	83	8	0.57	25	-6	0.058	-5	14	6.8	0.56	11.45
16	El-Amerya (B)	131	21	2.61	63	-32	0.258	4	17	36.1	0.39	27.93
17	Burg El-Arab (A)	132	17	0.72	53	-4	0.006	-20	37	16.4	0.71	16.15
18	Burg El-Arab (B)	143	21	0.57	63	-2	0.001	-26	47	14.8	2.38	17.15
19	West Noubaria (A)	70	6	0.57	19	-9	0.224	0.5	6	1.4	1.27	4.06
20	West Noubaria (B)	166	27	0.64	82	-32	0.152	-5	32	9.0	2.02	11.01
21	East Noubaria	80	8	0.57	24	-8	0.111	-3	11	4.5	0.40	12.12
22	El-Henwa	95	11	1.22	32	-3	0.009	-11	22	15.6	1.13	11.70
23	El-Mazraa	139	19	0.50	58	0	0.000	-27	46	18.6	2.37	16.36
24	El-Satah	70	7	0.10	20	0	0.010	-11	18	13.2	1.15	8.21
25	Wadi Sidr	118	14	0.43	42	0	0.014	-24	38	30.0	2.24	13.46
26	Wadi Sidri	169	32	0.40	97	-6	0.004	-38	70	44.7	2.12	19.92
27	Wadi Arab El-Soghier	115	13	0.50	39	-13	0.111	-5	17	19.7	2.27	6.87
28	Wadi El-Awag	65	5	0.10	16	-4	0.062	-3	8	3.0	0.38	8.74
29	Wadi Mehash	107	10	0.43	31	-12	0.150	-2	12	5.4	1.36	4.50
30	Wadi Abu-Gerf	57	5	0.00	15	-2	0.018	-5	10	3.0	0.47	7.88
	(b) Non-Calcareous soils:											
31	Meet-Kenana (A)	57	6	2.87	18	-8	0.197	0	6	9.8	0.47	8.40
32	Meet-Kenana (B)	36	3	0.43	10	0	0.040	-7	10	2.5	0.86	4.49
33	El-Dair	139	20	0.50	60	-5	0.007	-22	42	16.0	1.72	17.57
34	Benha (A)	149	24	0.72	73	-14	0.037	-19	43	20.1	1.37	20.96
35	Benha (B)	133	26	9.01	78	-70	0.805	35	0	63.9	0.17	48.07
36	Quesna	165	35	3.02	106	-63	0.353	15	20	27.3	1.00	16.72
37	Giza	153	25	0.64	76	-12	0.025	-22	47	20.8	1.74	20.32
38	Kom Ambo	93	10	0.79	29	-3	0.011	-10	20	10.3	0.84	11.72
39	Ganaklies (A)	89	10	0.93	29	-11	0.144	-2	12	8.5	0.30	16.80

P max. = adsorption P maximum (µg/g)
PBC = P buffering capacity (µg/g)
Exp. Desorp = EXP. desorption (µg/g)

n = binding energy
b = possible desorption (µg/g)
P-conc. = P- concentration of equilibium solution (mg/l)

Table (13): Simple correlation coefficients between P adsorption parameters with some soil characteristics and P-uptake by rye plants.

Tested Soils	Parameter	Van Huay paremeters					Langmuir parameters	
		P- max.	Exp. desorp.	n	b	p-conc.	K_1	K_2
All the tested soils	P-uptake	-0.027	0.612***	-0.040	-0.456**	0.414**	-0.205	0.286
	Clay	0.795***	0.069	0.837***	-0.224	-0.157	0.279	0.565***
	pH	-0.688***	-0.183	-0.674***	0.218	0.118	-0.325*	-0.449**
	Organic matter	0.721***	0.396*	0.757***	-0.460**	0.173	0.061	0.617***
	Fe-ox	0.763***	0.281	0.866***	-0.328*	0.087	0.194	0.678***
	Al-ox	0.756***	0.190	0.760***	-0.296	-0.060	0.296	0.580***
	Surface area	0.812***	0.137	0.809***	-0.287	-0.099	0.335*	0.574***
Non-Calcareous soils (<7% $CaCO_3$)	P-uptake	-0.210	0.518*	-0.252	-0.322	0.377	-0.129	0.060
	Clay	0.744***	-0.295	0.718***	0.015	-0.360	0.509*	0.278
	pH	-0.491*	0.404	-0.333	-0.247	0.490*	-0.614**	0.223
	Organic matter	0.628**	0.267	0.529*	-0.478*	0.222	0.098	0.320
	Fe-ox	0.796***	0.145	0.814***	-0.335	0.149	0.308	0.618**
	Al-ox	0.857***	-0.174	0.745***	-0.074	-0.252	0.613**	0.361
	Surface area	0.826***	-0.216	0.726***	-0.037	-0.300	0.578**	0.333
Calcareous soils (>7% $CaCO_3$)	P-uptake	-0.045	0.786***	-0.088	-0.548*	0.500*	-0.378	0.390
	Clay	0.833***	0.432	0.931***	-0.335	-0.012	0.088	0.814***
	pH	-0.885***	-0.474*	-0.849***	0.328	0.117	-0.300	-0.813***
	Organic matter	0.770***	0.498*	0.886***	-0.291	-0.019	0.022	0.884***
	Fe-ox	0.723***	0.174	0.910***	-0.040	-0.234	0.126	0.651**
	Al-ox	0.774***	0.346	0.905***	-0.248	-0.093	0.094	0.737***
	Surface area	0.872***	0.360	0.959***	-0.373	-0.017	0.184	0.747***

Table (13): Cont.

Tested Soils	Parameter	Van Huay paremeters P- max.	Exp. desorp.	n	b	p-conc.	Langmuir parameters K_1	K_2
Soils containing >40% clay	P-uptake	-0.765 **	0.866 ***	-0.676 **	-0.348	0.643 *	-0.087	0.034
	Clay	0.610 *	-0.587 *	0.630 *	0.167	-0.471	0.221	0.040
	pH	0.415	-0.150	0.295	-0.493	0.234	-0.453	0.680 **
	Organic matter	-0.056	0.203	0.075	0.075	0.167	-0.208	-0.293
	Fe-ox	0.625 *	-0.591 *	0.767 **	0.462	-0.544 *	0.228	0.002
	Al-ox	-0.121	-0.073	-0.152	0.109	-0.235	0.441	-0.295
	Surface area	0.626 *	-0.133	0.081	0.166	-0.263	0.334	-0.205
Soils containing <40% clay	P-uptake	0.144	0.644 ***	0.383 *	-0.635 ***	0.572 **	-0.455 *	0.465 *
	Clay	0.779 ***	0.251	0.796 ***	-0.455 *	0.181	0.156	0.524 **
	pH	-0.566 **	-0.200	-0.628 ***	0.255	-0.022	-0.231	-0.329
	Organic matter	0.258	0.242	0.300	-.317	0.235	-0.250	0.433 **
	Fe-ox	0.580 **	0.675 ***	0.715 ***	-0.656 ***	0.579 **	-0.062	0.785 ***
	Al-ox	0.653 ***	0.323	0.730 ***	-0.446 *	0.242	0.129	0.539 **
	Surface area	0.808 ***	0.237	0.840 ***	-0.467 *	0.185	0.252	0.526 **

*Where *, **, *** significant at 0.05, 0.01 and 0.001, respectively.*

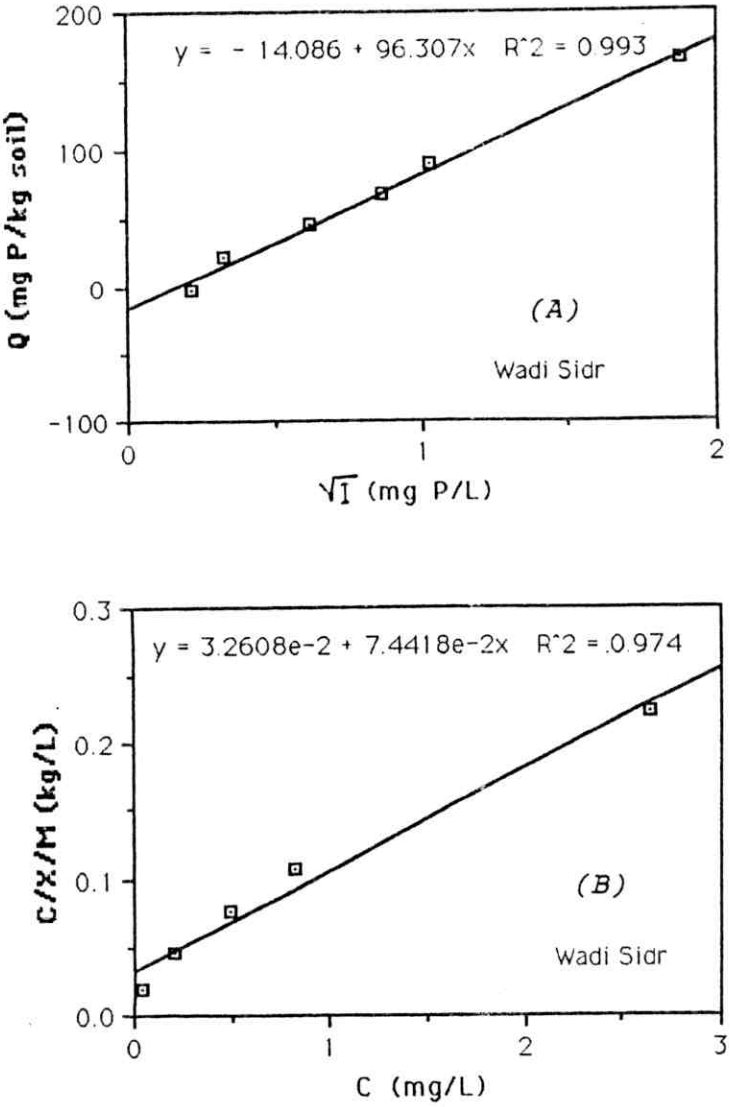


Fig. (12). Linearized form of sorption curves according to Van Huay (A) and Langmuir (B) isotherms for Wadi Sidr soil.

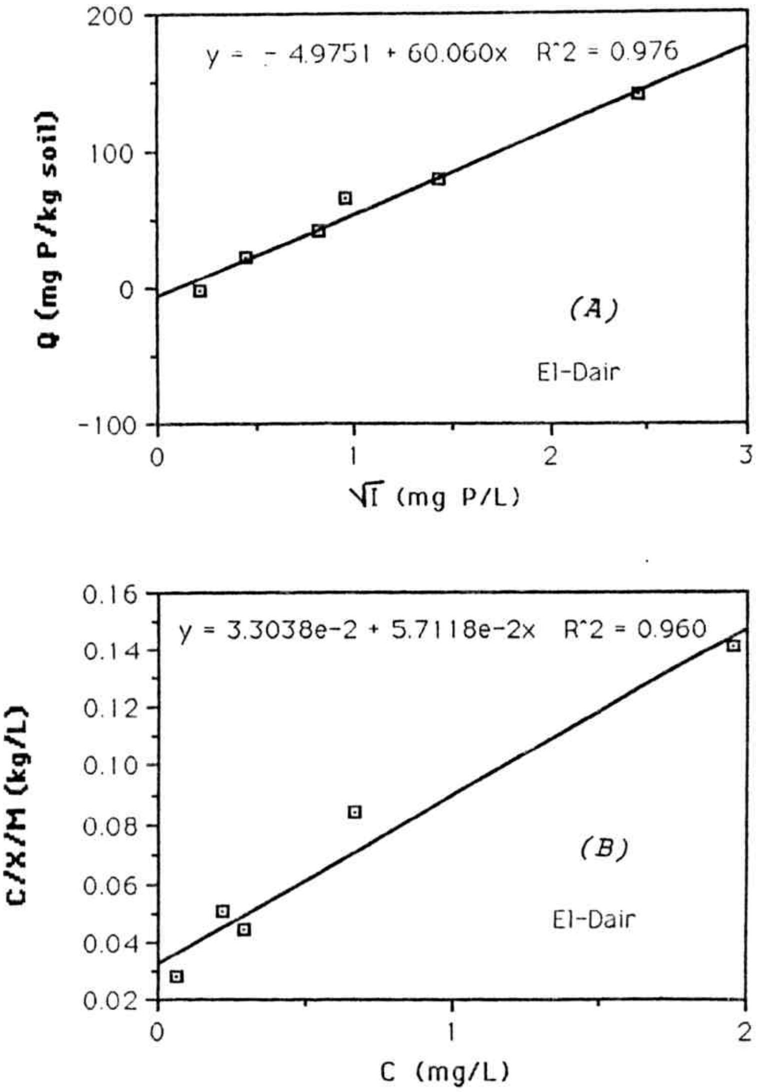


Fig. (13). Linearized form of sorption curves according to Van Huay (A) and Langmuir (B) isotherms for El-Dair soil.

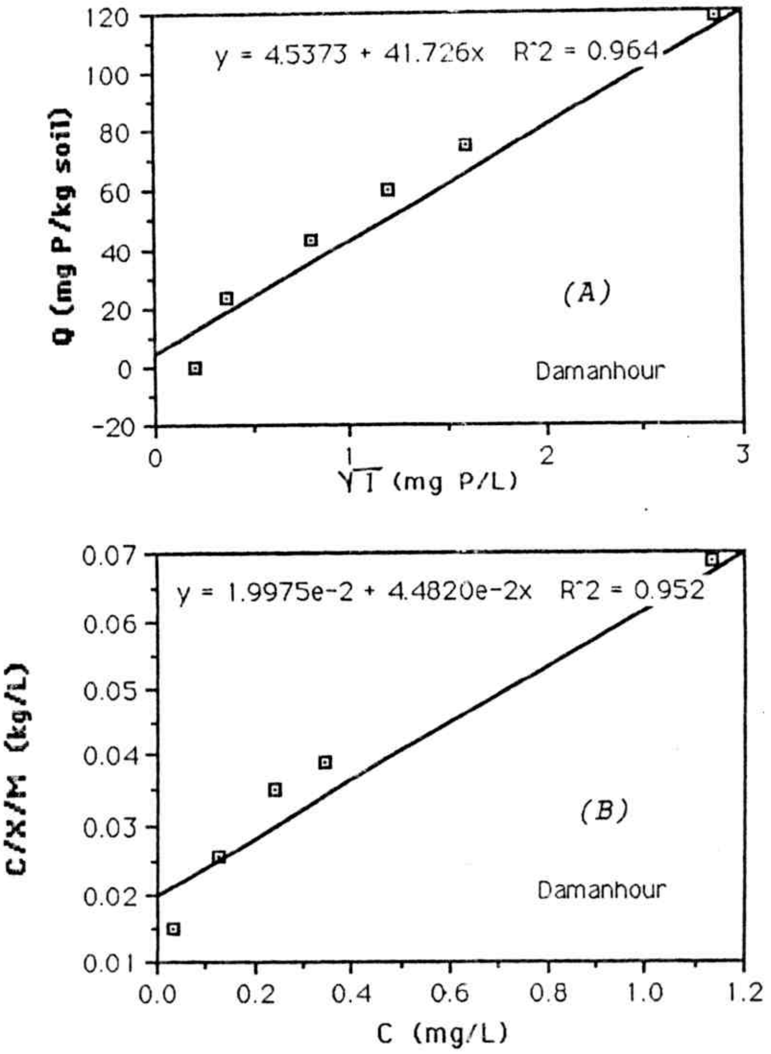


Fig. (14). Linearized form of sorption curves according to Van Huay (A) and Langmuir (B) isotherms for Damanhour soil.

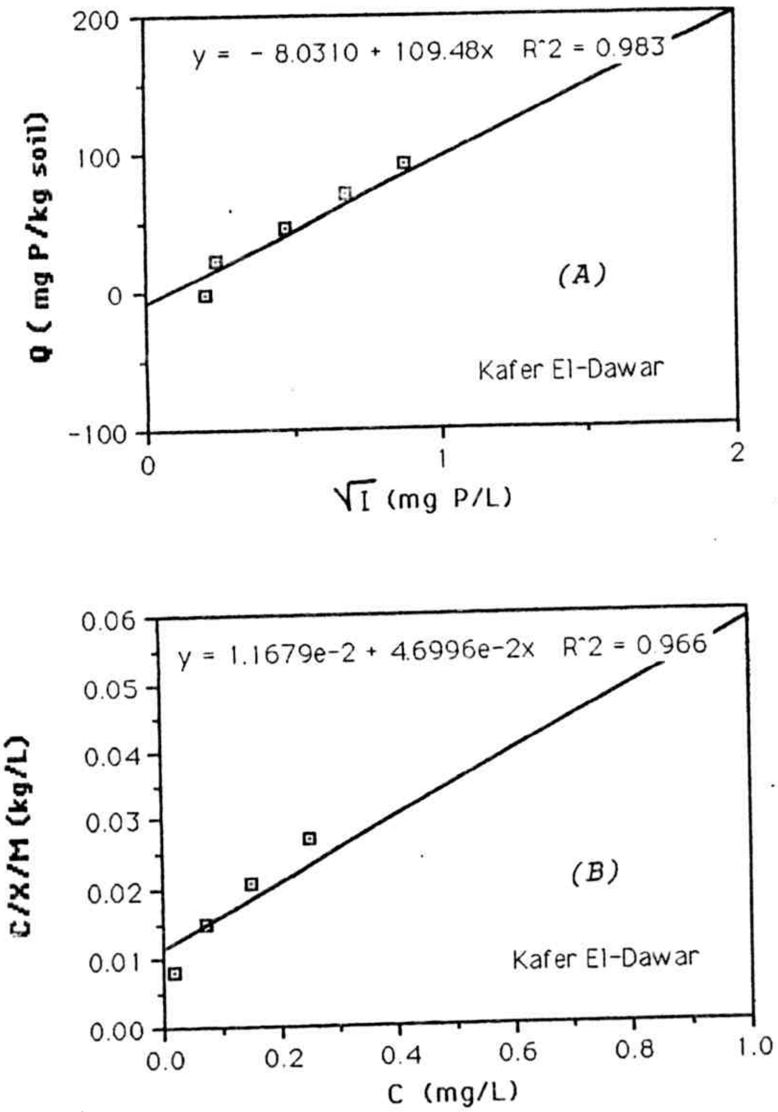


Fig. (15). Linearized form of sorption curves according to Van Huay (A) and Langmuir (B) isotherms for Kafr El-Dawar soil.

parameter (P max.) with the clay content in soils herein, (r = 0.795).

Data also show that the maximum P adsorption parameter, generally, correlated significantly and positively with each of soil organic matter (r = 0.721) , soil Fe-ox (r = 0.763) , soil Al-ox (r = 0.756) and surface area (r = 0.812). On the other hand, this parameter was highly significantly but negatively correlated with soil pH (r = - 0.688). Such "r" values might reflect the role due to organic matter, aluminum and iron contents as materials determining the soil capacity to maintain P availability to plants. Similar results were obtained by Mokwunye (1975), white and Taylor (1977), Bowden et al. (1980) and Sayin et al. (1990).

However, the correlation between the maximum P adsorption (P max) and the P-uptake by rye plants was found to be insignificant. This finding coincide with those of Sadik and Abd El-Aal (1978) and Abbas (1980). Such a trend could be explained on a basis that the successive amounts of P sorbed by the soils are retained at different affinities and hence are differing in their releasing abilities.

Data presented in Table (13) declare the correlation coefficient values that represent the relations between the adsorption P maximum and each of the studied soil characteristics.

Noteworthy mentioning that the results obtained for the non-calcareous soils followed the same trend of the calcareous ones, where the maximum P adsorption parameter correlated significantly with the different soil characteristics in both of the two soil categories . It is clear that the P max values correlated more significantly and negatively in the calcareous soils (r = - 0.885) than in the noncalcareous ones (r = - 0.491).

Concerning the relationship between P max and P uptake by rye plants, it is obvious that it was insignificant in both the calcareous and noncalcareous soils. This result coincide with those of the soils investigated herein as a whole.

Regarding effect of texture of the tested soils, it is clear that the P max correlated significantly with the clay content (r = 0.610), Fe-ox (r = 0.625) , and the surface area (r = 0.626) in the heavy textured soils, however, the corresponding values in the light textured soils were 0.779 , 0.580 and 0.808, respectively. Also, it is worthwhile to mention that the P max. correlated significantly and positively with Al-ox (r = 0.653) and significantly but negatively with the soil pH (r = -0.566) in the light textured soils, whereas insignificant correlations were achieved, in this concern, in the heavy textured soils.

Olsen and Watanabe (1957) and Udo and Uzu (1972) found that the P max. correlated significantly with the active surface area of the soil components. Rennie and Mc Kercher (1959) and Weir and Soper (1962) achieved similar correlations with the organic matter content of the soils while Abd El-Aal (1975) reported a significant relation between the P max. values and the clay content of some Egyptian soils.

Concerning the relationship of P max. with P uptake, A highly significant and negative relationship (r = - 0.765) was achieved in heavy textured soils.

4.4.1.2. *The affinity constant "n":*

The affinity constant "n", which is related to the bonding energy, could be calculated from the linear form of the Van Huay equation: $Q = n \sqrt{I} + b$ as the slope of this linear form.

Data presented in Table (12) show that values of this constant fluctuated between 10 and 161 with an average of 63. It is clear also that the highest value obtained was that of Ebees (a calcareous and heavy textured soil), while the lowest one was that of Meet-Kenana 'B' (a noncalcareous and light textured soil)

The mean values of this constant "n" in the noncalcareous, calcareous, heavy textured and light textured soils were 72 , 54 , 93 and 46 , respectively. It is clear that the higher values of the constant "n" were those of the heavy textured soils (> 40 % clay) while the lowest ones were those of the light textured ones (< 40 % clay).

Data of statistical analysis presented in Table (13) show that values of the constant "n" correlated highly significantly with clay content in the heavy textured soils (r = 0.837). This is true whether the examined soils were calcareous (r = 0.931) or noncalcareous (r = 0.718). Such a result confirms the aforementioned observations and ensure the proportional relation between the bonding energy and the clay content of the soils.

Holford (1980) and Loganathan et al. (1987) obtained almost similar results.

Concerning the relationship between values of P bonding energy and P uptake by rye plants, data show a significant, but negative, relationship in the heavy textured soils (r = - 0.676) while the relationship in the light textured ones was positive (r = 0.383) . Insignificant relationship in both the noncalcareous and calcareous soils was detected.

Abou El-Roos (1972), El-Rashidi (1972), Abd El-Aal (1975) and Abbas (1980) obtained insignificant relationship between P uptake and bonding energy. However, Abdou and Osman (1967) and Bakhoum (1971) established high significant and negative relationship between the P bonding energy and P uptake by plants from labile pool.

The inverse relation between soil pH and P bonding energy of the soils is also shown in Table (13). The correlation coefficient value "r" established between the P bonding energy of all the investigated soils and their corresponding pH values was negative and highly significant (r = - 0.674). The corresponding coefficient in the category of the noncalcareous soils was negative but significant (r = - 0.333).

On the other hand, the correlation coefficient value achieved in the calcareous soils was negative and highly significant (r = - 0.849).

Such results are expected since the increase in the P bonding energy should be associated, as mentioned by Mokwunye (1975), by a decrease in P availability which directly affected by P concentration in the equilibrium solution.

Data obtained reveal also that the organic matter content influenced, to a great extent, the P bonding energy, where the correlation coefficient between these two variables, within all the investigated soils, was positive and highly significant (r = 0.757). The correlation between the organic matter content and the P bonding energy was significant and higher in the calcareous soils (r = 0.886) than the noncalcareous ones (r = 0.529) however, this relationship was insignificant in both of the heavy textured and the light textured soils.

Regarding the relations between either of Fe-ox or Al-ox and P bonding energy, data show that the soil contents of these Al and Fe oxides affected significantly the P bonding energy where the "r" values between the P bonding energy (n) of all the investigated soils and both of the Fe-ox and Al-ox were 0.866 and 0.760, respectively.

No differences could be observed in this concern between the significancy achieved in the calcareous soils and the noncalcareous ones where the correlation coefficient values for Fe-ox and Al-ox were 0.910 and 0.905, respectively in the calcareous soils and 0.814 and 0.745, respectively in the noncalcareous ones.

It is clear that the texture of the tested soils seems to have no significant influence on the relation between the P bonding energy (n) and both of the Fe-ox and Al-ox where the "r" values achieved in either of the heavy or the light textured soils were almost equal (0.767 and 0.715 , respectively).

The surface area of the investigated soils seems to be of a greatest importance in increasing the P bonding energy, where the "r" value obtained for the relationship between the two variables was 0.809. The same relation was obtained in both of the calcareous (r = 0.959) and the noncalcareous (r = 0.736) soils.

In the heavy textured soils, which is characterized by high content of clay (> 40 %) the surface area did not correlate with P bonding energy. This indicates that P bonding energy in such soils may depend on some factors other than the specific area of the soil particles such as their content of the Fe-oxides. On the other hand, in the light textured soils, which contain < 40 % clay, the surface area played a more pronounced role in increasing the bonding energy, where the correlation coefficient obtained herein was 0.840.

4.4.1.3. Theoretical phosphate desorption constant "b" :

This constant is calculated as the intercept of the linear form of Van Huay equation. The values obtained for this constant , b , are presented in Table (12) . The results reveal that these values were relatively high in both categories of the noncalcareous and the heavy textured soils and lower in both categories of the calcareous and the light textured ones. The mean values of this constant (b) in the noncalcareous , calcareous , heavy textured and light textured soils were - 20 , -11 , - 20 and -12 , respectively.

Comparing the calculated values of phosphate desorption constant "b" with the experimentally determined ones may confirm the reliability of using the equation of Van Huay for calculating the phosphate desorption in such investigated soils.

Statistical analysis of these data ensure the significancy of the relation between this parameter and P uptake by plants from the tested soils as a whole (r = - 0.456) however, data show also that the relation between the two tested variables was significant, only in both categories of the calcareous soils (r = -0.548) and the light textured ones (r = - 0.635).

It is seen from data in Table (13) that phosphate desorption parameter (b) was not affected by the clay content of the investigated soils, except in the category of the light textured ones where a significant correlation was achieved (r = - 0.455) . Also, soil pH , Al-ox content, and surface area of the investigated soils were not correlated with P desorption parameter (b), at any level of significancy except in the category of the light textured soils where significant correlations were achieved between "b" values and each of the Al-ox content (r = - 0.446) and surface area of the soils (r = - 0.467).

On the other hand, P desorption parameter significantly but negatively correlated with each of the organic matter content (r = - 0.460) and the Fe-ox content (r = - 0.328), however, the correlations were not significant neither in the noncalcareous nor in the calcareous soils.

The aforementioned results may throw lights on the role of the clay fraction, Fe-ox, Al-ox and surface area as soil components of the light textured soils as factors limiting, to a great extent, the phosphate desorption parameter of such soils.

4.4.1.4. *Potential P release and P fertilizer supply required:*

The potential P release can be calculated from the linear form of Van Huay equation as follows: **Potential P release = − (n $\sqrt{}$ I + b)** while P supply required as fertilizer can be calculated as follows: **P fertilizer required = (n $\sqrt{}$ I + b)**

Data presented in Table (12) show the values of these two parameters calculated for the different investigated soils. It is logic to notice that the higher the values of the potential P release is, the lower is the P fertilizer supply required. Importance of such calculated parameters can not be neglected from the practical point of view, especially, in the field of soil fertility and fertilization. This could be considered as an additional advantage of Van Huay equation (1975) in the chemistry of phosphorus in soils.

4.4.2. *The P adsorption parameters calculated from Langmuir equation:*

The data obtained for P adsorption by the different soil samples are presented in Table (12). These data were used for plotting the Langmuir adsorption isotherm in the linear form proposed by Olsen and Watanabe (1957). Noteworthy remembering that Rennie and Mc Kercher (1959) referred that constants calculated from this isotherm permit a sound theoritical approch to some of the problems of P sorption by soils. However, it should be put in mind that the supposed monolayer adsorption is not the solely mechanism responsible for P sorption.

The following parameters, that are related to P sorption, were examined and tested for reliability to serve as parameters for assessing soil P availability.

4.4.2.1. Initial soil surface phosphorus (s):

This parameter refers to the amount of P initially sorbed by the soil surfaces and was calculated after Abd El-Aal (1975) by subtracting the values of water soluble P extracted from the soil from the corresponding values obtained by the anion resin at the same soil-water ratio.

Data in Table (12) show that values of this parameters fluctuated between 1.4 and 63.9 and averaged 32.2 ppm. The calculated values were significantly correlated with the P uptake by plants in the investigated soils as a whole ($r = 0.428$) , however, the correlation between the two variables in each of the investigated soil categories was not significant, except the heavy textured soils ($r = 0.593$) .

Such a result may give an evidence to the role played by the surface P in characterizing the availability of P to plants and is in agreement with the results of Abd El-Aal (1975) and Abbas (1980).

4. 4.2.2. *The maximum P adsorption (K_2):*

The values obtained for the maximum P adsorption of the investigated soils are presented in Table (12). These values ranged from 4.49 up to 48.07 with an average of 17.5 µg P/g soil.

Statistical analysis data presented in Table (13) show that the correlation between the values obtained for this parameter and P uptake by plants grown on the investigated soils, generally, was insignificant (r = 0.286) except in the category of the light textured soils where the correlation coefficient achieved was significant (r = 0.465). Such result indicate that the maximum P adsorption can not be considered as a promising parameter for assessing P availability in soils.

Regarding the relation between the investigated parameters and the clay content of all the studied soils, it can be noticed that the two variables correlated significantly (r = 0.565). This result is in accordance with the results reported by Rennie and Mc Kercher (1959), Sadik and Abd El-Aal (1978) and Abbas (1980).

On the other hand, data in the same Table show that the correlation between values of the maximum P adsorption and clay content of the noncalcareous soils category as well as that of the heavy textured soils category was insignificant.

Data in Table (13) show a quite close relationship between P adsorption maximum and each of the pH, organic matter content, Fe-ox, Al-ox and surface area of the investigated soils as a whole, where the "r" values obtained were -0.449 , 0.617 , 0.678

, 0.580 and 0.574, respectively. However, it could be noticed that among the aforementioned characteristics, the Fe-ox content was the solely characteristic which correlated significantly with the P adsorption maximum of the noncalcareous soils category where the "r" value was 0.618. On the other hand no significant correlation could be achieved in the category of the heavy textured soils.

4.4.2.3. The bonding energy constant (K_1) :

Table (12) show that values of this constant (K_1) ranged from 0.17×10^{-4} to 2.56×10^{-4} with an average of 1.32×10^{-4} . The K_1 constant was negatively and significantly correlated with P uptake by plants grown on the tested soils as a general trend. However, such significancy could be observed between these two variables only in the category of the light-textured soils ($r = -0.455$).

Regarding the effect of soil properties on the bonding energy, data in Table (13) show that the pH values and surface area were only the factors that affected, generally, the P bonding energy where they correlated significantly with this parameter ($r = -0.325$ and 0.335 , respectively) However, additional factors such as clay content, and Al-ox content seem to play effective role in determining P bonding energy in the noncalcareous soils.