DISTRIBUTION AND TRANSFORMATION OF PHOSPHORUS FORMS IN SOIL AFTER LONG-TERM APPLICATIONS OF P FERTILIZER AND CROP RESIDUES

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ABSTRACT

Two rates of crop residues (-CR and +CR) and six rates of P fertilizer (0, 100, 200, 300, 400, and 500 kg superphosphate fed^{-1}) were applied each growing season (corn and clover) in a long-term field experiment started at the Experimental Farm of Assiut University, Assiut, Egypt. The crop residues were added to the soil at the end of each growth season at rates of 5.45 and 3.71-ton fed^{-1} corn stover and Egyptian clover straw.

The response of soil P fractions to both CR and superphosphatr fertilizer was small at the very beginning of the experiment, however it became more pronounced starting from the year 1999 up to the year 2003. Resin-P accounted for 0.81- 0.93%; and 1.30- 1.52% of total P in soil after 5 and 16 years of continuous application of CR and SP, respectively. At zero level of SP and no addition of CR the resin-P fraction was markedly decreased from 6.5 to 5.65.

The size of inorganic (P_i) and organic (P_o) phosphorus forms of the $NaHCO_3$ fractions were increased with the continuation of applying the P fertilization management for 16 years and ranged from 2.73 to 3.13 and from 1.84 to 2.19 for P_i and P_o forms, with and without crop residues, respectively. Five years after continuous application of SP and without application of CR, the relative concentrations of $NaOH$-P_i and $NaOH$-P_o increased from 3.69 to 4.44% and from 1.60 to 2.00% of total P, respectively. Also, increasing the application level of SP from zero (P_0) to 500 kg SP fed^{-1} (P_5) each growth season for five years increased the HCl-P and residual-P fractions linearly and significantly.

The path analysis showed that both resin-Pi and $NaHCO_3$-P_i were mainly and directly affected by P fertilization. In soil that received P fertilization management with CR, resin-P was largely controlled by added-P_i, $NaHCO_3$-P_i and HCl-P fractions.
Keywords: Long term, crop residues, P fertilizer, P fractions and P transformation.

INTRODUCTION

Phosphorus exists in soils in different fractions of great diversity in size and availability. The size of each fraction is controlled and changes with type of soil, plant, climate and agricultural practices, the most important of them are P fertilization practices, organic manuring, soil moisture contents, and time (Aulakh *et al.,* 2003). According to Stewart and Sharpley (1987) inorganic P forms are associated with amorphous and crystalline sesquioxides, and calcareous compounds. Organic P forms include relatively labile phospholipids and fulvic acids and more resistant humic acids. As mentioned by Stewart and Tiessen (1987), P forms are not discrete entities, as integrates and dynamic transformations between forms occur continuously to maintain equilibrium condition.

In their recent works, Rubaek and Sibbesen (1993, 1995) showed that Po extracted by the resin revealed changes induced by drying and rewetting and biocidal treatments, and reflected seasonal variations in soil related to differences in P fertilization. Using the macroporous anion-exchange resin

extraction, Guggenberger *et al.* (1996) found that the soil under grass had the largest amount of resin P_o and diester-P, indicating a rapid turnover of P_o with building-up of a large potentially labile, microbial derived P_o pool. The amount of resin P_i appeared to be a   primarily function of fertilization, and amounted to around 100 mg kg^{-1} in the fertilized soils irrespective of the soluble organic matter content and P source.

Application of fertilizer P and organic manure for many years resulted in accumulation of Pi and Po fractions in the soil (McKenzie *et al.,* 1992[a] and [b]; Schmidt *et al.,* 1996). Reddy *et al.* (1996) and Singh *et al.* (2001[a,b]) reported that the application of farmyard manure with fertilizer P enriched long-term P fertility of a Vertisol through enhancement in organic P content and a short-term P supply as recalcitrant P. In the most P-deficient soils under crop production, P fertilization over a long time increased both organic and inorganic P fractions (Richards *et al.*, 1995). These effects depend on the rates and forms of P fertilizers applied. The addition of P in the manure resulted in increasing the $NaHCO_3$-P_i and decreasing the NaOH-P_i (Mnkeni and MacKenzie, 1985; Xie *et al.,* 1991; Zhang and MacKenzie 1997). Soil NaOH-P_i is held strongly by chemisorption to Fe and Al components of soil (Ryden *et al.,* 1977) and is considered as moderately labile P. The addition of organic material to that soil tended to decrease P sorption, possibly due to competition between phosphate ions and organic anions for retention sites in the soil (Hue, 1991; Iyamuremye *at al.,* 1996a). Zhang and MacKenzie (1997) reported that changes in soil Po fractions displayed different patterns between fractions and between inorganic fertilizer P levels. Their data showed that $NaHCO_3$-P_o decreased with added manure, probably due to accelerated mineralization caused by addition of organic C. On the other hand, the NaOH-P_o fraction increased rapidly at first then slowly in relation to added fertilizer P.

Soil P transformations vary depending on soil type, climatic conditions, and management practices. In Mollisols, labile P was associated with inorganic bicarbonate and hydroxide extractable P, while in Ultisols, labile P was largely in the organic P forms (Tiessen *et al.,* 1984). Assessing the turn over rates of ^{33}P added in soybean residues to soils from three experimental sites in Michigan, Daroub (1994) found that the largest fraction of the applied ^{33}P was found in the inorganic labile form, which decreased with time accompanied by an increase in the NaOH fraction in all three soils tested.

MATERIALS AND METHODS

In 1988 a field experiment with corn- clover cropping system was started at the Experimental Farm of Assiut University, Assiut, Egypt. The soil of the experimental site is alluvial clay (37% clay and 33% silt) with pH 7.79, ECe 2.96ds/m, OM 1% and 5.12 ppm total Olsen P. Crop residues of corn (cv single cross 10) and the plant materials of the last cut of Egyptian clover were used as sources of organic materials, for long term, in P fertilization management. By the end of each growth season, the corn stover and the plant materials of the last cut of Egyptian clover were dried out in the open field, cut to small pieces and ploughed into the surface layer (0.00- 0.25m depth) of the experimental site. Two rates of crop residues (without,-CR and

with,+CR) and six rates of P fertilizer (0, 100, 200, 300, 400, and 500 kg super phosphate fed^{-1}) were applied each growth season. The crop residues were added to the soil at the end of each growth season at rates of 5.45 and 3.71 ton fed^{-1} corn stover and Egyptian clover straw. The treatments were arranged in a split-plot design with crop residues (CR) in the main plots and P fertilizer in the sub-plots of 3.0 m x 3.5 m each. Each treatment was replicated four times and laid out in the same plot each growth season, each year starting from 1988 up to 2003.

Fertilizer P (superphosphate 15.5% P_2O_5) was applied broadcasting and thoroughly mixed with the top 0.00 - 0.25 m surface soil layer immediately before sowing of each crop. All plots received the recommended agricultural practices and doses of N (105 kg N fed^{-1} added to corn plants) and K fertilizers (50 kg K_2O fed^{-1} for each of corn and clover) every year.

Total soluble salts were determined in the saturated soil-paste extract by measuring the electrical conductivity (Jackson, 1973). Organic matter content was determined using Walkely-Black method, following Baruah and Barthakur (1997). Soil pH was measured in 1:1 (soil: water) suspensions using a glass electrode (Jackson, 1973). Mechanical analysis was carried out using the pipette method (Piper, 1950). Olsen P extraction (Olsen *et al.,* 1954) with 0.5 M $NaHCO_3$ (pH 8.5, 1: 20 soil: extract ratio, 30 min shaking) was prepared and a portion was digested with potassium persulphate as described by Bowman (1989) and analyzed for total Olsen's extracted P (P_{Ot}).

The soil samples collected successively in years 1992, 1996, 1999 and 2003 after harvesting corn were thoroughly mixed, air-dried and ground to pass a 2-mm sieve and stored for chemical analysis and P fractionation. A modified version of Hedley *et al.* (1982) procedure as described by Zhang and MacKenzie (1997) was used to sequentially fractionate soil P (Fig. 1).

Duplicate soil samples of 1.00 gm soil passed through a 2-mm sieve were extracted sequentially as outlined in Fig. 1. Soil samples were placed, each, in a 50-ml centrifuge tube with a resin bag (containing 0.4 g of Dowex 1-X8 anion exchange resin in bicarbonate-saturated form) and 30-ml of distilled water was added and shacked for 16 h, then the resin bags were collected and the adsorbed Pi was desorbed using 20 ml of 0.5 M HCl solution as described by Nziguheba *et al.* (1998). After that, soil samples were extracted sequentially with 30 ml of each 0.5 M $NaHCO_3$ (pH 8.5), 0.1 M NaOH, and 1.0 M HCl by shaking the samples for 16 h, consecutively after shaking, the suspensions were centrifuged for 30 min at 6000 rpm and then filtered through 0.45µ filters. Total P was determined by digestion of the whole soil sample (1.00g soil) with 5 ml concentrated H_2SO_4 and 5 ml H_2O_2 at 360 °C. The residual-P was calculated as difference between total P and sum of other fractions. A portion of the $NaHCO_3$ and NaOH extracts was acidified to precipitate the extracted organic matter and the supernatant was analyzed for P_i (Zheng *et al.,* 2002). In addition, another portion of $NaHCO_3$ and NaOH extracts was digested with potassium persulphate as described by Bowman (1989) and analyzed for P_t. The concentration of organic $NaHCO_3$-P_o and NaOH-P_o were calculated as the difference between those of P_t and P_i. The P_i concentration in extracts was determined colorimetrically using phosphomolibdic-stannous chloride system as described by Jackson (1973).

Fig. 1. Modified procedure after Hedley *et al.* (1982) for P fractionation.

The data obtained of soil P fractions were subjected to standard analysis of variance and the means of treatments (crop residues and P fertilization rates) over years were tested for significant differences using least significant difference at $P = 0.05$. The CALIS statistical procedure of SAS statistical analysis program (SAS Institute, 2000) was used to derive the path coefficients between the P pools in the conceptual models. This statistical procedure also tests how well conceptual models represent graphic interpretations of P transformations in soil. Fit Goodness Index and Chi-square Test were used to assess model fit (SAS Institute, 2000; Zheng *et al.,* 2002).

RESULTS AND DISCUSSIONS

The changes in soil P fractions following the seasonal additions of crop residues (CR) and inorganic P fertilizer (SP) for 5 and 16 years are presented in Tables 1 and 2, respectively. Continuous application of CR and SP for 5 years increased the size of resin-P, $NaHCO_3$-P and NaOH-P fractions; although the changes were small; they were significant. However, the more stable P fractions (HCl-P and residual fractions) showed no significant responses to continuous application of CR and SP during the first 5 years. After 16 years of continuous application of CR and SP, all P fractions were significantly increased. At low level of inorganic P fertilization, resin-P, $NaHCO_3$-P_i and HCl fractions (the inorganic P fractions) were mostly affected by the incorporation of CR into the 0.25 cm upper soil layer (Tables 1 and 2). However, with increasing the level of SP, these fractions were mostly affected by the inorganic P fertilizer (SP). This is in harmony with the data obtained by Saleque *et al.* (2004), they found that the concentrations of $NaHCO_3$ soluble P, NaOH extracted inorganic P (P_i) and acid P were affected under treatments with high proportions of organic fertilizers.

1-Resin-P:

The changes in resin-P as affected by continuous application of CR and SP over the laps of 16 years were significant. Resin-P accounted for 0.81- 0.93%; and 1.30- 1.52% of total P in soil after 5 and 16 years of continuous application of CR and SP, respectively.

Resin-P increased linearly and significantly ($p \leq 0.05$) with increasing the rate of SP application. The sharp increases were continuous with continuous application of SP from the year 1992 (Table 1) to the year 2003 (Table 2). These effects on resin-P were emotively enhanced by the incorporation of CR into the 0.25 m surface soil layer, and became more pronounced after 16 years of continuous application of CR and SP (Fig. 2).

The magnitude of the resin-P fraction linearly increased with long-term application of both CR and SP. These results confirm the earlier findings of Aulakh *et al.* (2003) whose results emphasized that the soil content of resin-P increased successively with each increment of applied P, and Motavalli and Miles (2002) observed that long-term application of inorganic P fertilizer or manure for 111 years significantly increased resin-P among different cropping systems compared with the unfertilized control and the native prairie site.
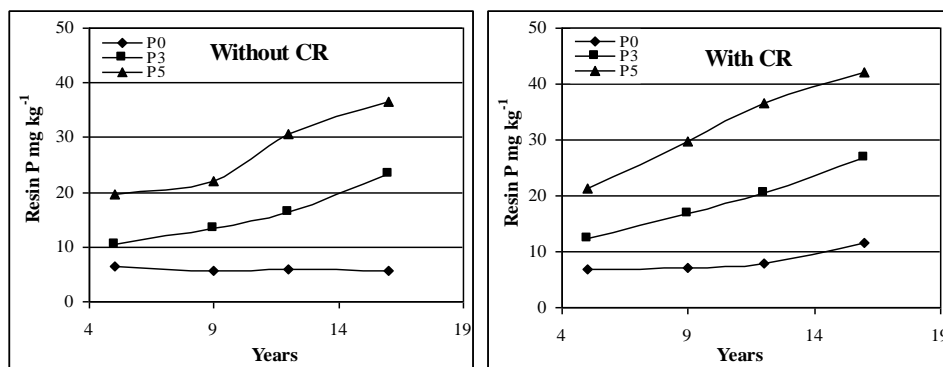
Po = 0.00, P3= 300, P5= 500 kg SP fed^{-1} each growth season and CR= crop residues.

Fig. 2. Effects of long-term (16 years) application of P fertilizer (SP) and crop residues on resin-P fraction.

Application of CR to plots that received zero level of SP increased the concentration of resin-P from 6.5 to 6.89 mg P kg^{-1} after 5 years of continuous application of CR (Table 1), and from 5.75 to 11.56 mg P kg^{-1} after 16 years of continuous application of CR (Table 2). It seems that organic matter application to soil not only increases the more soluble P fractions, but also decreases the P binding affinity by soils and increases P desorption capacity (Sui and Thompson, 2000). These processes finally increase the magnitude of resin-P pool which is available to plant uptake. The competition between organic anions (resulting from the decomposition of CR) and phosphate anions for the same sites of adsorption increased the amount of phosphate anion desorbed into the soil solution (Nziguheba *et al.*, 1998).

Table 1. Effect of crop residues and P fertilization on P fractions in soil at the end of summer growth season, 1992 (continuous application for 5 years).

Treatments		Resin	NaHCO$_3$		NaOH		HCl	Residual
			P$_i$	P$_o$	P$_i$	P$_o$		
		mg P kg^{-1}						
Without crop residues	P$_0$	6.50	18.64	8.51	43.83	18.97	386	705
	P$_1$	7.11	23.25	8.63	48.28	22.97	400	741
	P$_2$	8.23	29.45	11.91	52.51	24.37	412	750
	P$_3$	10.52	30.57	13.3	59.58	27.28	432	800
	P$_4$	13.65	37.23	15.18	63.75	28.56	457	834
	P$_5$	19.62	44.50	16.75	68.84	31.0	493	878
Mean		**10.94**	**30.61**	**12.38**	**56.13**	**25.53**	**430**	**785**
With crop residues	P$_0$	6.89	20.45	9.31	45.94	22.92	390	692
	P$_1$	8.23	24.75	10.14	51.88	24.72	409	734
	P$_2$	10.9	33.75	12.5	55.97	28.22	416	768
	P$_3$	12.5	36.19	15.0	68.84	30.41	441	804
	P$_4$	17.11	48.00	16.22	74.06	33.98	473	835
	P$_5$	21.35	55.13	17.0	81.88	39.1	488	886
Mean		**12.83**	**36.38**	**13.36**	**63.10**	**29.89**	**436**	**787**
LSD 0.05	CR	0.85	1.90	1.02	2.11	0.25	NS	NS
	P	0.93	1.39	1.16	1.81	1.50	20	6.15
	CR× P	1.45	2.56	NS	3.08	1.95	NS	10.50

P$_0$= 0.00, P$_1$= 100, P$_2$= 200, P$_3$= 300, P$_4$= 400, P$_5$= 500 kg SP fed^{-1} for each growth season.
P$_i$= Inorganic phosphorus, P$_o$= Organic phosphorus,
CR= Crop residues, P= Phosphorus, NS= Non significant.

Table 2. Effect of crop residues and P fertilization on P fractions in soil at the end of summer growth season, 2003 (continuous application for 16 years).

Treatments		Resin	NaHCO$_3$		NaOH		HCl	Residual
			P$_i$	P$_o$	P$_i$	P$_o$		
		mg P kg^{-1}						
Without crop residues	P$_0$	5.75	20.20	11	39.25	14.75	293	756
	P$_1$	13.57	32.93	24.83	74.0	32.23	528	807
	P$_2$	15.64	39.83	29.55	78.0	34.4	536	820
	P$_3$	23.45	47.03	33.23	85.38	38.93	558	840
	P$_4$	29.48	57.90	36.6	88.83	43.13	626	890
	P$_5$	36.52	62.78	41.1	95.45	50.55	693	973
Mean		**20.74**	**43.45**	**29.39**	**76.82**	**35.67**	**539**	**848**
With crop residues	P$_0$	11.56	32.85	27.24	75.75	27.45	438	764
	P$_1$	16.75	43.65	31.93	88.5	38.43	513	827
	P$_2$	21.45	46.40	34.2	96.7	43.35	528	860
	P$_3$	26.77	56.05	35.0	102.6	56.5	558	912
	P$_4$	37.74	64.43	44.9	102.8	65.31	648	917
	P$_5$	42.15	78.53	51.63	105.4	73.5	734	1008
Mean		**26.07**	**53.65**	**37.48**	**95.29**	**50.76**	**570**	**881**
LSD 0.05	CR	1.73	1.67	0.78	2.39	1.69	15	5.15
	P	1.31	1.63	1.53	1.57	1.61	36	5.57
	CR× P	2.36	2.63	2.10	3.05	2.62	48	8.68

P$_0$= 0.00, P$_1$= 100, P$_2$= 200, P$_3$= 300, P$_4$= 400, P$_5$= 500 kg SP fed^{-1} for each growth season.
P$_i$= Inorganic phosphorus, P$_o$= Organic phosphorus,
CR= Crop residues, P= Phosphorus.

2- Bicarbonate extractable P (NaHCO$_3$-P):

Soil NaHCO$_3$-P fraction includes the water-soluble and the freely exchangeable P, and represents a considerably readily and potentially available P for plant uptake (Aulakh *et al.,* 2003; Bowman and Cole, 1978). Examination of the data presented in Table (1) reveals that the size of this

fraction was relatively small and ranged between 3.18 and 3.61% of total P, 26.86 - 28.80% of it was in the organic form, $NaHCO_3$-P_o.. After 16 years of continuous application of P fertilization managements (Table 2), the relative size concentration of this fraction rose up and ranged between 4.57 and 5.32% of total P.

During the years of this experiment, $NaHCO_3$-P forms linearly and significantly ($p \leq 0.05$) increased due to the increasing levels of SP, the incorporation of CR into the surface 0.25 m soil layer, and their interaction (Fig. 3). The sizes of these fractions were significantly increased with incorporating the CR into the P fertilization management, and became noticeably higher. The concentrations of $NaHCO_3$-P_i, and $NaHCO_3$-P_o in plots that received the highest level of SP with CR for 5 years were 55.13 and 17.0 mg P kg^{-1}, respectively (Table 1).
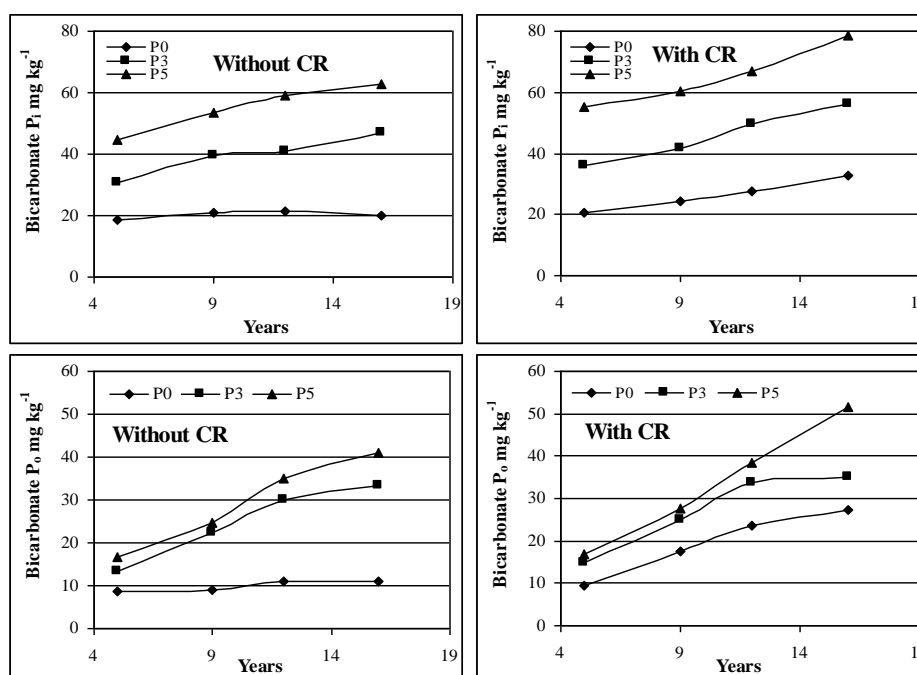

Fig (3): Effect of long term (16 years) application of P fertilizer (SP) and crop residues on $NaHCO_3$-P fractions.

Continuous incorporation of CR into the surface 0.25 m soil layer drastically improved the amount of $NaHCO_3$ extractable P. This indicates the transformation of crop residues P (inorganic and organic) to more labile forms (inorganic and organic) with time. However, the size of the $NaHCO_3$-P_o was more affected especially in the absence of mineral P fertilization. In plots that received no SP, the changes in the concentration of $NaHCO_3$-P_i over the lapse of 16 years due to the incorporation of CR were less than that of $NaHCO_3$-P_o (Table 2). In plots with zero level of mineral P fertilizer, most of

$NaHCO_3$-P resulted from the decomposition of CR, which remained in the organic form, giving rise to the size of $NaHCO_3$-P_o pool. With high levels of SP, the accumulation of $NaHCO_3$-P exceeded the levels of available P that are recommended for most field crops (Cope and Rouse 1980). This may arise the potential of ground and surface water pollution.

The increase in $NaHCO_3$-P due to the application of CR was comparable to the increase that occurred due to SP, which further suggests that continuous pplication of CR may partially substitute for mineral P fertilizer. These results indicate that the size of labile $NaHCO_3$-P fraction can be conspicuously increased by the combination of SP fertilizer and CR. Using the crop residues for long time as a partial substitution for mineral P fertilizers could be an acceptable P fertilization management. Seasonal application of CR in combination with a low rate of mineral P fertilizer (not more than 100 kg SP fed[-1]) could maintain the level of available labile P pools (Table 2, P_i= 43.6 and P_o= 31.9 mg P kg^{-1}) in soil at the recommended level for most field crops. This, in turn, leads to reducing the coast of input of the production system, and the potential pollution of either ground or surface water resources.

3- Sodium Hydroxide extractable P (NaOH-P):

Incorporation of CR into the surface 0.25 m soil layer, application of SP, and their interaction significantly ($p \leq 0.05$) increased the concentration of NaOH-P forms in all years of study (Fig. 4). The application of increased levels of SP linearly and significantly increased the concentration of both NaOH-P_i and NaOH-P_o. This was further magnified with incorporation of CR into soil. A similar increase in NaOH-P_i in soil due to organic matter addition was reported by Sharpley *et al.* (1984) and Iyamuremye *et al.* (1996b).
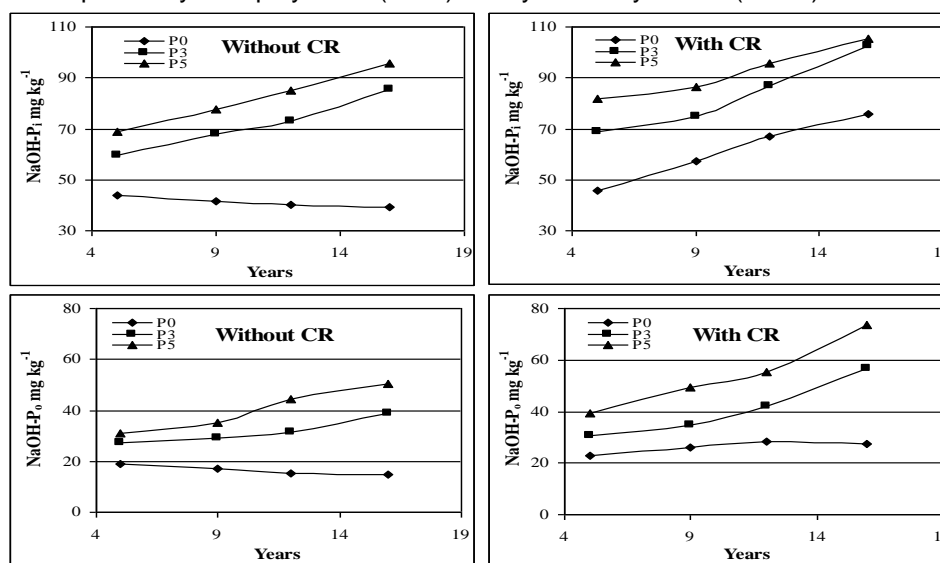
Po = 0.00, P3= 300, P5= 500 kg SP fed[-1] each growth season and CR= crop residues.
Fig. 4. Effects of long-term (16 years) application of P fertilizer (SP) and crop residues on NaOH-P fractions.

The magnitudes of changes of NaOH-P forms were variable based upon the presence of CR or not, and the duration of applying the P fertilization management. At the beginning of the experiment (5 years after starting the experiment, Table 1) the changes in the relative size of NaOH-P_i and NaOH-P_o as a result of incorporation of CR were in the favorer of NaOH-P_i form, which mean that most of P applied either as inorganic or organic form was transformed to the NaOH-P_i pool.

After 16 years of continuous application of SP and CR (Table 2), the situation was changed. The changes in relative size of NaOH-P_o form due to the application of CR and SP were more noticeable, which means that most of the P added to soil entered into the NaOH-P_o pool. Data obtained by Saleque *et al.* (2004) showed that the concentration of NaOH-P_i was lowest under treatments that contained no organic additions and a larger concentration of NaOH extracted P_i was observed under treatments with organic fertilizers.

Increasing the rate of SP application increased the rate of accumulation of both NaOH-P forms, although the rates of changes in the concentrations of NaOH-P_i were not altered much without the incorporation of CR. However, in the presence of CR the rate of changes in NaOH-P_o was considerably higher than that in the absence of CR (Fig. 4).

Comparing the concentrations of NaOH-P forms with the concentrations of resin-P and $NaHCO_3$-P forms in the zero SP plot (Tables 1 and 2), which almost remained constant over the time, proved that some transformations from NaOH-P_i and/or mineralization of NaOH-P_o to resin-P and $NaHCO_3$-P may have occurred during the lapse of experiment, 16 years. These results are similar to those reported by **Zhang (1996).**

4- Acid extractable P (HCl-P) and residual P:

The relative size of HCl-P and residual-P fractions varied from 25 to 35% and 48 to 66% of total P, respectively. At the very beginning of the experiment, continuous incorporation of CR into the surface 0.25 m surface soil layer had no significant effect on the HCl-P or residual-P (Table 1). However, the size of the HCl-P pool and residual-P fraction, after 16 years of continuous application of CR and SP, were significantly (*p*≤0.05) increased due to continuous application of CR, SP and their combination (Table 2 and Fig. 5).

The incorporation of CR into the surface 0.25 m soil layer stimulated the effects of increasing levels of SP on the concentrations of both HCl-P and residual-P fractions. HCl-P constitutes stable Ca-bound P (Williams *et al.,* 1980), while residual-P pool is likely composed of in the humus fraction (Stewart *et al.,* 1980) and insoluble inorganic P forms. It seems that, these two pools together constitute the storage pools of P in most of the Egyptian soils, and is expected to be transformed into the more soluble forms when the amount of P taken up by plants exceeds the amount of P fertilizers added to soil.

As a result of plant uptake, the readily- and moderately-labile P pools, which are in equilibrium with the HCl-P fraction, were depleted, and some of the less soluble HCl-P fraction eventually transformed to the other more soluble fractions, causing the recorded decreasing of HCl-P pool.
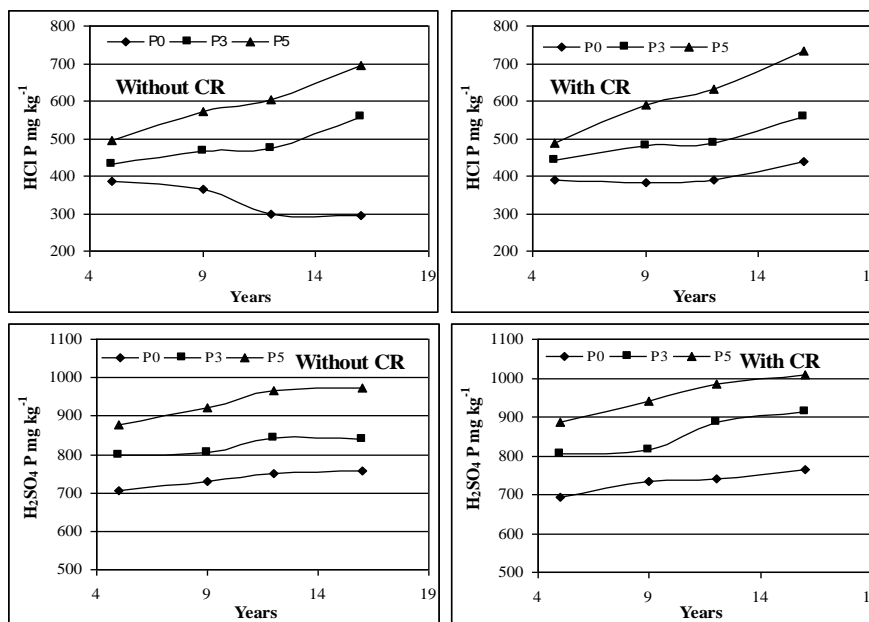
Po = 0.00, P3= 300, P5= 500 kg SP fed⁻¹ each growth season and CR= crop residues.

Fig. 5. Effects of long-term (16 years) application of P fertilizer (SP) and crop residues on HCl-P and residual P fractions.

Long-term effects of P fertilization managements on P transformation in soil:

In both P fertilization managements, added mineral P fertilization (P_i) was positively related with all P pools (Table 3 and 4). In soil received no CR (-CR) the correlations between added P_i and P_i pools (resin-P_i, NaHCO$_3$-P_i, and NaOH-P_i) were high, but the correlation between added P_i and NaHCO$_3$-P_i was the highest. This means that in the absence or with low input of organic matter, most of mineral P fertilizer has intered into the mineral forms. Using the crop residues in the P fertilization management, the correlations between added P_o and the organic pools (NaHCO$_3$-P_o, NaOH-P_o) and NaOH-P_i were stronger and more associated (the r values were 0.83, 0.60 and 0.73 for NaHCO$_3$-P_o, NaOH-P_o and NaOH-P_i, respectively). The presence of increased amount of P_o in the P fertilization management resulted in building up the P_o pools, which considered as a protected form against the precipitation and/or adsorption processes, and thus increased the availability of P in soil. In both P fertilization managements, resin-P was positively related with other P pools, but it was highly correlated with NaHCO$_3$-P_i. This may be because resin-P and NaHCO$_3$-P_i are a part of the same soil pool, which considered as a labile P pool.

3242

In agreement with the results reported by Zheng *et al.* (2002), the residual-P was strongly associated with Pi added, but was less related to Po added, which means that this pool consists mainly of inorganic forms of P.

Table 3. Pearson's correlation coefficients for soil P fractions as influenced by the addition of inorganic P fertilizer (coefficients significant at $p \leq 0.05$ are shown).

	Resin-P	NaHCO₃-Pᵢ	NaHCO₃-Pₒ	NaOH-Pᵢ	NaOH-Pₒ	HCL-P	Residual-P	Added Pᵢ
Added Pᵢ	0.94	0.98	0.91	0.90	0.93	0.89	0.94	1.00
Residual-P	0.93	0.95	0.83	0.86	0.87	0.86	1.00	
HCL-P	0.92	0.91	0.87	0.93	0.92	1.00		
NaOH-Po	0.91	0.93	0.92	0.97	1.00			
NaOH-Pᵢ	0.90	0.93	0.94	1.00				
NaHCO₃-Pₒ	0.89	0.90	1.00					
NaHCO₃-Pᵢ	0.95	1.00						
Resin-P	1.00							

Added Pᵢ= Inorganic P added

To investigate the effects of P fertilization managements on soil P pools and their transformations, the path relationships between different soil P pools as affected by P fertilization managements were constructed taking into account the two different P sources i.e. the mineral P fertilizer (added-Pᵢ) and the organic P of CR (added-Pₒ). Resin-P is an estimate of the utmost soluble form of P in soil solution, while the residual-P is considered as the ultimate main storage form of P that mainly consisted of tightly bound-Pᵢ and -Pₒ. The other P fractions are transformed mutually and continuously to resin-P and/or residual-P, the processes that are controlled by climatic factors, agronomic practices, and soil conditions. Thus the different P pools are conceptually grouped into soluble P (resin-P), labile and moderately labile Pᵢ and Pₒ (NaHCO₃-Pᵢ and -Pₒ), low labile Pᵢ and Pₒ (NaOH-Pᵢ and –Pₒ), acid-P, and residual-P. The impact of mineral P fertilizer (added-Pᵢ) and the P of CR (added-Pₒ), as independent variables on resin-P, NaHCO₃-Pᵢ, NaHCO₃-Pₒ, NaOH-Pᵢ, NaOH-Pₒ, HCl-P and residual-P, as dependent variables were, therefore, explored using standardized multiple linear regression and path analysis using SAS PC version 8.2 (SAS institute, 2000). First, simple Pearson's correlations between P fractions were calculated (Table 3 and 4) and the standardized regression coefficients (β, path coefficient) of each relation was calculated.

The conceptual model for each P fertilization management was drawn illustrating the transformations among P pools in soil (Fig. 6 and 7). In the path diagrams, a straight single-headed arrow indicates a direct causal path. Indirect causal effects are connoted by a variable being linked to a given dependent variable via one or more intermediary variables. The path coefficients (numbers on lines) indicate the relative magnitudes of the direct effects of the explanatory variables linked to each dependent variable.

Table 4. Pearson's correlation coefficients for soil P fractions as influenced by the addition of inorganic P fertilizer and crop residues (coefficients significant at $p \leq 0.05$ are shown).

	Resin-P	NaHCO$_3$-P$_i$	NaHCO$_3$-P$_o$	NaOH-P$_i$	NaOH-P$_o$	HCl-P	Residual-P	Added P$_i$	Added P$_o$
Added P$_o$	0.49	0.44	0.83	0.73	0.60	0.52	0.44	0.46	1.00
Added P$_i$	0.98	0.95	0.83	0.86	0.96	0.94	0.94	1.00	
Residual-P	0.95	0.97	0.79	0.89	0.91	0.90	1.00		
HCl-P	0.95	0.92	0.83	0.84	0.92	1.00			
NaOH-P$_o$	0.95	0.92	0.88	0.89	1.00				
NaOH-P$_i$	0.87	0.88	0.90	1.00					
NaHCO$_3$-P$_o$	0.83	0.79	1.00						
NaHCO$_3$-P$_i$	0.97	1.00							
Resin-P	1.00								

Added P$_i$= Inorganic P added; Added P$_o$= Crop residues P added.

In the soil that received no CR (Fig. 6) 95.3% of the variability in resin-P was accounted for the variation in added-P$_i$ and the size of NaHCO$_3$-P$_i$, NaHCO$_3$-P$_o$, and residual-P. The path analysis shows that both resin-P$_i$ and NaHCO$_3$-P$_i$ were mainly and directly affected by P$_i$ fertilization with path coefficients (β) of 0.89 and 1.0, respectively, which mean that resin-P acts as a sink for P$_i$ that came from added-P$_i$ and directly transformed from residual-P. The added-P and residual-P consist the main and direct source to replenish the depletion in resin-P as a result of plant uptake. The NaOH-P$_i$ form was significantly, negatively and directly affected by P$_i$ addition (β = -0.98), but positively and indirectly responded to P$_i$ fertilization through NaHCO$_3$-P$_i$ (β = 1.88 x 0.92) and through NaHCO$_3$-P$_i$ and NaOH-P$_o$ (β = 1.88 x 0.88 x 1.10). This means that added-Pi was transformed indirectly through the NaHCO$_3$-P$_i$ pool into NaOH-P$_i$ (β =1.88 x 0.92), and through NaHCO$_3$-P$_i$ and NaOH-P$_i$ pools into HCl-P (β = 1.88 x 0.92 x 0.66).

The direct effect of NaHCO$_3$-P$_i$ on resin-P was not significant (β = not significant), but resin-P was significantly and indirectly affected by NaHCO$_3$-P$_i$ through residual-P (β = 1.76 x 0.40). It appeared that resin-P and NaHCO$_3$-P$_i$ pools worked as a sink for soluble P$_i$ that came directly from added-P$_i$, and through the transformation of residual-P. The path coefficient between NaHCO$_3$-P$_i$ and NaHCO$_3$-P$_o$ was negative (β = -1.06). The negative sign of the path coefficient emphasized that the NaHCO$_3$-P$_i$ was immobilized to replenish the decrease of NaHCO$_3$-P$_o$; especially in the absence of low input of inorganic P. Organic P pools (NaHCO$_3$-P$_o$ and NaOH-P$_o$) have non-significant direct effect on resin-P.

Resin-P and NaOH-P$_i$ have significant and direct effects on HCl-P (β = 0.47, and 0.66, respectively). These results suggested that the HCl-P acted as sink for labile and moderately-labile P present in excess of plant removal, probably through the formation of Ca-phosphate. This means that a large portion of available P was transformed into secondary minerals, this result

support the theory that secondary P minerals are formed in the soil at the expense of more labile P_i forms. The HCl-P was considered as a secondary sink for residual fertilizer P in an Alfisol (Agbenin and Goladi, 1998) as well as a calcareous soil (Daroub *et al.,* 2000).

The $NaHCO_3$-P_o was directly affected by NaOH-P_i (β = 1.53), and indirectly through NaOH-P_o and NaOH-P_i (β = 0.88 x 1.10 x 1.53), which means that a part of the inorganic P pool was transferred into the organic P pool. The biological immobilization of P_i through microbial activities and that associated with roots activities could be the direct causes for such kind of transformation. Therefore, path analysis clearly showed that under the condition of no and/or low addition of organic P sources mineral forms of P tended to transform into organic forms (P_o). Schmidt *et al.* (1996) and Simard *et al.* (1995) reported a larger amount of NaOH-P_o in agricultural soils that received a surplus of P_i addition concerning plant needs. They suggested that, with high P_i fertilizer rates in excess of plant removal, the excess P was supposed to reduce the phosphorelase activity and consequently reduce the mineralization of NaOH-P_o, with the final result of increasing the size of NaOH-P_o pool.

Residual-P was indirectly and significantly affected by added-Pi through $NaHCO3$-P_i (β = 1.88 x 1.76). The other P pools have no significant direct effects on residual-P.

In soil that received the P fertilization management with CR (Fig. 7), resin-P was largely controlled by added-P_i, $NaHCO_3$-P_i and HCl-P fractions (β =0.46, 0.28 and 0.22, respectively) and 97.4% of the variability in resin-P is accounted for by the variations in these variables. This means that in the presence of OM, both $NaHCO_3$-P_i and HCl-P_i are easily transformed into resin-P and these P pools consist the main source for replenish the depletion in resin-P caused by plant uptake. The NaOH-P_i fraction has no significant effect on resin-P, while it has a high correlation with resin-P (r= 0.87). This was due to its indirect effect through $NaHCO_3$-P_i (β = 0.33 x 0.28). The $NaHCO_3$-P_i was not significantly and directly affected by Pi fertilization, but it indirectly responded to P_i fertilization through residual-P (β = 5.48 x 0.85).

The NaOH-P_i was positively related to residual-P (β = 0.99) and negatively related to resin-P (β = -0.42) fractions. In this P fertilization management the increase in residual-P and the decrease in resin-P were associated with the increase in NaOH-P_i. The NaOH-P_i was directly affected by added- P_o (β = 0.47). This may be due to the abilities of the NaOH extract solution to dissolve the organic compounds.   This result concurs with Sui *et al.* (1999), whose results revealed that the order of the rate of increases in concentrations of P fractions with each increment of P applied with biosolids was NaOH-P_i > $NaHCO_3$-P_i ≈ HCl-P > NaOH-P_o > H_2O > residual P > $NaHCO_3$-P_o.

The $NaHCO_3$-P_o and NaOH-P_o fractions positively responded to added- P_o (β = 0.46 and 0.20, respectively). The path coefficient showed that $NaHCO_3$-P_o was more affected by the added-P_o.

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The negative effects of $NaHCO_3$-P_o and NaOH-P_o on the residual-P (β = -1.9 and -2.45, respectively) partly support the idea that the crop residues application tended to promote the accumulation of $NaHCO_3$-P_o and NaOH-P_o fractions in the soil. In the same context, the negative effect of $NaHCO_3$-P_o on residual-P (β = -1.9) and the positively effect of NaOH-P_o on $NaHCO_3$-P_o (β = 0.37), suggested that the addition of crop residues accelerates the mineralization of moderately labile P_o into labile P_o.

The positive effects of NaOH-P_o and $NaHCO_3$-Pi on HCl-P (β = 0.71and 0.68, respectively) and the negative effect of HCl-P on residual-P (β = -1.51), suggest that the HCl-P was a reservoir of soil P as well as a source for plant P uptake, presumably through equilibration with resin-P (β = 0.22). The $NaHCO_3$-P_o was directly affected by HCl-P (β = 0.28). Mineralization of CR resulted in increasing the solubility of secondary Pi forms, and releasing soluble and organic P of low molecular weight and hence may represent an easily accessible P source for microbes (Beck and Sanchez, 1994). The path analysis showed that the residual-P act as a sink for Pi and Po fertilization (β = 5.48 and 1.75, respectively), as well as long-term reservoir of P equilibrations with other P fractions.

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توزيــع و تحـولات الصـور المختلفـه للفوسـفور فـى التربــه تحـت تـأثير الاضـافات المسـتمره لبقايا المحاصيل و السماد الفوسفاتى

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تم استخدام معدلين من بقايا المحاصيل (بدون وبإضافة بقايا المحاصيل) و6 مستويات من السـماد الفوسـفاتي, سـوبر فوسـفات, (0, 100, 200, 300, 400 و 500 كجـم سـوبر فوسـفات للفدان), أضيفت لكل من المحصـولين (الـذرة والبرسـيم), تم خلـط بقايا المحاصيل بالطبقة السـطحية للتربـة (0.00 – 0.25 م) عند انتهاء كل موسم نمو(3.71 , 5.45 طن للفدان من حطـب الـذرة و قش البرسيم , على التوالي).

استجابة صـور الفوسـفور لإضـافة كـل من بقايا المحاصيل والسوبر فوسفات كانت قليلة إلى حد ما في بداية التجربة, على الرغم من أنها أصبحت أكثر ملاحظة بداية من سنة 1999 الـى سنة 2003. التغيرات في Resin-P كانـت معنويـة نتيجـة للإضـافات المسـتمرة مـن بقايا المحاصيل والسـوبر فوسـفات لمـدة 16 سـنة. كانـت نسـبة الـ Resin-P مـن الفوسـفور الكلـى في التربـة من0.81– 0.93% و 1.3– 1.52% بعد 5 و 16 سنة من الإضافات المستمرة لبقايا المحاصيل والسوبر فوسفات, على التوالي. انخفض ال Resin–P من 6.5 الى 5.6 جزء فى المليون عند إستخدام المستوى صفر من السوبر فوسفات و بدون إضافة بقايا المحاصيل.

إزداد حجم الصـورة العضوية والمعدنية للفوسفور المستخلص ب NaHCO3 مـع إسـتخدام الإدارة للتسميد الفوسفاتي لمدة 16 سنة وتراوحت هذه القيم من 2.73 إلى 3.13 ومن 1.80 إلى 2.19 للصـورة المعدنية و العضـوية, مـع إضـافة وعدم إضـافة بقايا المحاصيل, علـى التوالـى. أدت الإضـافات المسـتمرة للسـوبر فوسـفات لمـدة خمس سنوات بدون إضـافة بقايا المحاصيل إلى زيادة التركيزات النسـبية للـ NaOH-Pi و   NaOH-Po مـن 3.69 إلى 4.44% ومن 1.60 إلـى 2.00% من الفوسفور الكلى, على التوالى . كمـا أن زيادة مستويات السـوبر فوسفات المضافة من صـفر (P0) إلى 500 كجم للفدان(P5) لكل موسم نمو,لمـدة خمس سنوات أدت إلـى زيادة كلاً من HCl-P و residual–P زيادة معنوية و خطية.

أوضح استخدام تحليل المسـار(path analysis) أن resin-P و   NaHCO3-Pi تـأثرت بشـكل مباشـر ومعنـوي بالسـماد الفوسـفاتي0 في إدارة التسـميد الفوسـفاتي مـع إضـافة بقايا المحاصيل, تـأثر resin-P بشـكل كبير بكـل مـن السـماد المعدني المضـاف و NaHCO3-Pi و 0HCl-P