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LONG-TERM UTILIZATION OF CROP RESIDUES FOR IMPROVING P STATUS IN SOIL

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ABSTRACT

A long term field experiment with corn- clover cropping system was started in 1988 at the Experimental Farm of Assiut University, Assiut, Egypt, to develop an integrated P management model for sustained crop production on the soil type of that experimental farm.

To achieve such goal, the treatments included two rates of crop residues (0 and CR) and six rates of fertilizer P (0, 100, 200, 300, 400, and 500 kg superphosphate fed^{-1}) which were applied to both corn and Egyptian clover. The crop residues were incorporated into the surface (0.00-0.25 m) soil layer at the end of each growth season (5.45 and 3.71 ton fed^{-1} corn stover and Egyptian clover straw, respectively).

The continuous incorporation of corn stover and clover straw each year for 16 years linearly increased soil organic matter (SOM) from 1.23 to 2.39%. However, there was a slight increase in SOM content in the plots received no CR, on average, from 1.00 to 1.23%. The magnitude of changes of Olsen's extractable P forms was associated with the application rates of superphosphate and the incorporation of crop residues into the soil. As a result of increasing the rate of P fertilization up to 77.5 kg P_2O_5 fed^{-1}, either with incorporation of crop residues or not, the level of available P reached higher values that could be hazardous for pollution of ground water or surface water.

Keywords: Soil organic matter, long term, available phosphorus, crop residues.

INTRODUCTION

Long-term experiments have shown the benefit of manure, crop residues, adequate fertilization, and crop rotation on maintaining agronomic productivity by enhancing organic matter (OM) input into the soil. Reduced and zero tillage, set-aside, perennial crops are other recommended management practices commonly recognized as preserving or increasing soil organic carbon (Freibauer *et al.,* 2004; Lal, 2004; Paustian *et al.,* 1997; Smith, 2004).

The effect of crop residues addition on the increase of soil organic matter may depend upon the amount of residues added, quality of the residues, environment and the duration of addition (Kumar and Goh, 2000). Addition for a short-term duration in hot climates, promoting rapid decomposition, may lead to only a slight or no increase in soil organic matter (Aggarwal *et al.,* 1997). In contrast, long-term addition has been shown to increase organic carbon (Perucci *et al.,* 1997).

In a field experiment, Guled *et al.* (2002$_a$ and $_b$) found that organic carbon percent was significantly increased after three years of application of crop residues. However, Mubarak *et al.* (2003) observed that a two-year application of crop residues had no significant effect on organic carbon content, being ascribed to fast decomposition of organic matter in tropics and hence need longer than 30 months (study period) for the accumulation of organic matter.

Phosphorus availability and efficiency of inorganic P fertilizers utilization by plants were markedly enhanced when P fertilizers were incorporated with organic manure or crop residues before planting (Hue, 1990). Decomposition of crop residues can further increase P availability by releasing CO_2, which forms H_2CO_3 in the soil solution, resulting in the dissolution of primary P-containing minerals (Tisdale *et al.,* 1985). Also, the released organic acids during decomposition of organic manures and crop residues may help in dissolving soil mineral P (Sharpley and Smith, 1989). In soils with high P-fixing capacity, organic compounds released during decomposition processes may increase P availability by blocking P-adsorption sites (Easterwood and Sartain, 1990) or via anion exchange (Kafkafi *et al.,* 1988). Organic manure or crop residue probably reduce the P sorption capacity and, hence, increase P concentration in the equilibrium solution (Bumaya and Naylor, 1988).

Research works carried by Aulakh *et al.* (1991 and 2003) and Picone *et al.* (2003) emphasize that long-term application of P fertilizers significantly increased Olsen-P, accumulated residual fertilizer P in soil and accelerated its conversion to non-labile P forms. After 16 years of application of P fertilizer; Olsen-P was accounted for 55-66% of the total P accumulated in soils (Whalen and Chang, 2001).

This work shows the effect of continuous addition of P fertilizers and crop residues for a period of 16 years on improving the soil content of organic matter and the availability of P for plants.

MATERIALS AND METHODS

A field experiment with corn- clover cropping system was initiated in 1988 at the Experimental Farm of Assiut University, Assiut, Egypt, to develop an integrated P management system for sustained crop production on the alluvial clay soil of that experimental farm. Important characteristics of the soil (0- 0.25 m depth) are listed in Table 1.

The experiment was designed to verify using, on a long-term base, the crop residues of corn (cv single cross 10) and the plant materials of the last cut of Egyptian clover as sources of organic materials in P fertilization management. Each year, by the end of the growth seasons, 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. The treatments included two rates of crop residues (-CR and +CR). 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, respectively, and six rates of P fertilizer (0, 100, 200, 300, 400, and 500 kg super phosphate fed^{-1}), for each of the two growing seasons. 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.

Crop residues were applied 15- 30 days before sowing of corn or Egyptian clover, and then the soil was irrigated and ploughed again. The nutrient composition of CR was slightly variable from one year to another, and on average, residues of both corn and Egyptian clover, contained 36% total C, 0.7-1.23% N, 0.22% P and 0.83% K on a dry weight basis. 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.

Table 1. Selected physical and chemical properties of the experimental soil

Properties	**Values**
Particle size distribution	
Clay %	47
Silt %	33
Sand %	20
Soil texture	Clayey
pH (1: 1) suspension	7.79
Organic matter %	1.0
ECe dS/m	2.96
Soluble cations (meq/L):	
Ca^{++}	7.63
Mg^{++}	8.82
Na^+	15.13
K^+	0.61
Soluble anions(meq/L):	
$CO_3^= + HCO_3^-$	4.41
Cl^-	15.14
$SO_4^=$	13.10
$NaHCO_3$ extractable (ppm):	
P_{Ot}	5.12
P_{Oi}	4.00
P_{Oo}	1.12
DTPA extractable (ppm):	
Fe	7.47
Mn	14.00
Zn	1.03
Cu	2.52

Total soluble salts were determined in the saturated soil-paste extract by a measuring the electrical conductivity (Jackson, 1973). The same extract was used to determine various soluble cations and anions.

Soluble cations: calcium and magnesium were titrated by versene (Baruah and Barthakur, 1997), while sodium and potassium were measured by a flamephotometere (Jackson, 1973).

Soluble anions: carbonates and bicarbonates were titrated by 0.01 N HCl, chloride was measured by titration with silver nitrate solution (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).

DTPA extractable Fe, Mn, Zn and Cu in soil samples were extracted according to Baruah and Barthakur (1997). Using an atomic atomic absorption

Mechanical analysis was carried out using the pipette method (Piper, 1950).

The soil samples collected after corn harvest in the years of 1990 up to 2003 were analyzed for Olsen P extraction (Olsen *et al.,* 1954) with 0.5 M $NaHCO_3$ (pH 8.5, 1: 20 soil: extract ratio, 30 min shaking). A portion of the $NaHCO_3$ extract was analyzed for P_i inorganic Olsen's extracted P (P_{Oi}). In addition, another portion of $NaHCO_3$ extract was digested with potassium persulphate as described by Bowman (1989) and analyzed for total Olsen's extracted P (P_{Ot}). The concentration of organic Olsen's extracted P (P_{Oo}) was calculated as the difference between P_{Ot} and P_{Oi}. Phosphorus was determined using the stannous chloride method as described by Jackson (1973).

RESULTS AND DISCUSSION

1- Long-term effects of incorporation of crop residues (CR) on soil organic matter (SOM):

During the first two years of the experiment (from 1988 to 1990), no change in soil organic matter (SOM) in the plots received no CR was detected, being almost constant and ranged between 1.00 and 1.33% (Table 2). The continuous cultivation system of corn-clover crop rotation overcame the exhausting processes of SOM, stabilized and significantly increased the level of SOM from 1.00 to 1.33% with a rate of accumulation close to 0.025% year^{-1}. The small increases in SOM in plots receiving no CR could be attributed to the repeated crop rotation in the same plots for 16 years, as well as to greater root biomass caused by better crop growth (Manjaiah and Singh, 2001). Liang and Mackenzie (1994) reported that the content of soil organic C increased by 7% after 3 years and by 18% after 6 years of continuous corn.

However, at the very beginning of the experiment from year 1988 to 1990, there was slight increase in SOM content in the plots received CR, on average, from 1.00 to 1.23%. From year 1990 and later on until year 2003 the incorporation of crop residues in the surface layer (0.00-0.25 m) had a remarkable effect on the amount of SOM. Soil organic matter was significantly ($p \leq 0.05$) increased with continuous incorporation of crop residues in the surface (0.00- 0.25 m) soil layer from 1.23% in 1990 to 2.39% in 2003 (Table 2 and fig. 1).

The regression of SOM percent over years shows that incorporation of corn stover and clover straw increased the SOM in the surface 0.25 m soil layer at a rate of 0.083% per year (Fig. 1). This rate was almost 4 times higher than in plots that received no CR (0.03 % per year). The percent of SOM was considered as one of the most important properties that improved soil quality. Using a legume-based system for 5- 13 years increased the input of organic carbon by more than 415 kg C h^{-1} year^{-1} (Ohno *et al.,* 2005).

Table 2. Effects of incorporation of crop residues (CR) on soil organic matter (SOM).

Year		Without CR	With CR	Mean
		Organic matter (%)		
1990		1.00	1.23	**1.11**
1991		1.06	1.29	**1.17**
1992		1.06	1.35	**1.20**
1993		1.18	1.39	**1.29**
1994		1.23	1.43	**1.33**
1995		1.23	1.53	**1.38**
1996		1.24	1.58	**1.41**
1997		1.24	1.63	**1.43**
1998		1.25	1.73	**1.49**
1999		1.26	1.83	**1.54**
2000		1.29	1.93	**1.61**
2001		1.32	2.06	**1.69**
2002		1.33	2.20	**1.76**
2003		1.33	2.39	**1.86**
Mean		**1.21**	**1.68**	**1.44**
LSD 0.05	**CR**	0.03	0.03	**0.03**
	Y	0.01	0.01	**0.01**
	CR× Y	0.03	0.03	**0.03**

CR= Crop residues Y= Year

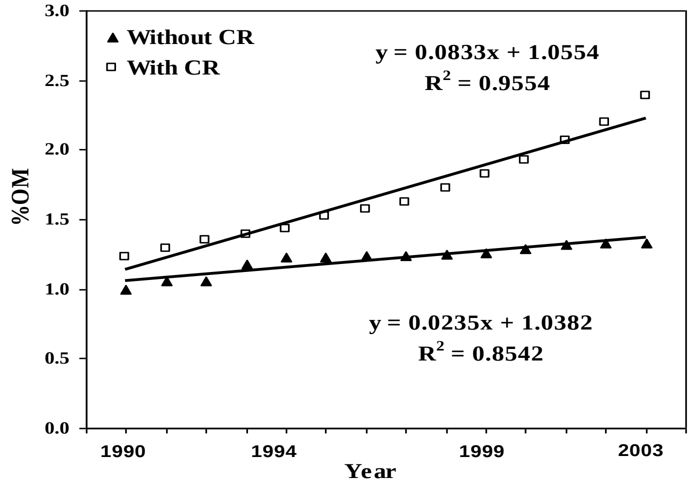


Fig. 1. Effects of incorporation of crop residues (CR) on soil organic matter (SOM).

Cultivated soil under continuous mixed pasture had higher organic carbon (OC) contents than the non-cultivated soil (control plot) (Rosell *et al.*, 2000). Sharma *et al.* (2005) reported that long-term application of sorghum stover had great effects on the physical and chemical properties of Alfisol, and application of sorghum stover proved superior to no residues treatments in maintaining higher soil quality index (SQI).

2- Long-term effects of P fertilization and/or crop residues on Olsen's P forms:

Olsen's extractable P forms were linearly and significantly, ($p \leq 0.05$) changed with continuous application of SP and/or crop residues. The magnitude of changes of Olsen's extractable P forms was associated with the application rates of SP and the incorporation of crop residues into the soil. In the plots receiving no crop residues, total Olsen's extractable P (P_{Ot}) after 16 years of application of 100, 200, 300, 400, and 500 kg SP fed^{-1} each growth season was increased compared to the level at year 1990 by calcalateion 6.40, 8.87, 18.12, 23.61 and 30.62 mg kg^{-1}, respectively (Table 3, Fig. 2). In the presence of crop residues, the corresponding increases in P_{Ot} were even higher. The values of relative increases were 10.00, 15.62, 23.62, 33.37 and 38.87 mg P kg^{-1}, respectively. The response of inorganic (P_{Oi}, Table 4) and organic (P_{Oo}, Table 5) Olsen's extractable P to continuous application of SP plus crop residues followed the same trend; however, the changes in P_{Oi} were higher than those obtained in P_{Oo}. Thus, the changes in P_{Ot} were much attributed to the changes in P_{Oi}. The higher Olsen-P contents in the combined treatment of chemical fertilizer plus crop residues, seems to be partially due to additional supply of P through the microbial decomposition of crop residues (Singh *et al.,* 2007). These increases in Olsen's P could also be attributed to the reducing effects of organic matter on P sorption due to the competition between PO_4^{3-} ions and organic anions for P retention sites in the soil (Xie *et al.,* 1991). Perrott (1978) suggested that the increase in negative charges in the soil was due to selective adsorption of organic molecules containing a greater concentration of anionic group. These organic molecules not only compete for sorption sites with orthophosphate ions but also increase negative charges, which results in a higher orthophosphate concentration in solution.

Changes in Olsen's extractable P forms over the span of 16 years gave a clear picture for the importance of using the crop residues and P fertilization management in keeping the level of available P around the limits needed by most crops. In the soil that received neither P fertilization nor crop residues both P_{Oi} and P_{Oo} were markedly reduced, and P_{Ot} (2.12 mg P kg^{-1}) reached the deficient level. Continuous incorporation of crop residues in soil for 16 years with no application of SP helped to keep the level of available P (P_{Ot}, 7.2 mg P kg^{-1}) near the critical limit (9- 12 mg P kg^{-1}). With the application of SP alone at a rate as low as 100 kg fed^{-1} (15.5 kg P_2O_5 fed^{-1}) each growth season for 16 years, the total available P (P_{Ot}) reached the level of 11.53 mg P kg^{-1}, which is fall within the critical limits for most crops. Incorporation of crop residues made that level approached 15.13 mg P kg^{-1}, which is mostly marginal for all crops. This emphasizes the importance of continued application of organic matter in reducing the amount of mineral P fertilizer that is needed for crop production. Increasing the rate of P fertilization up to 77.5 kg P_2O_5 fed^{-1}, either with incorporation of crop residues or not, the level of available P reached higher values that could be hazardous for pollution of ground water or surface water.

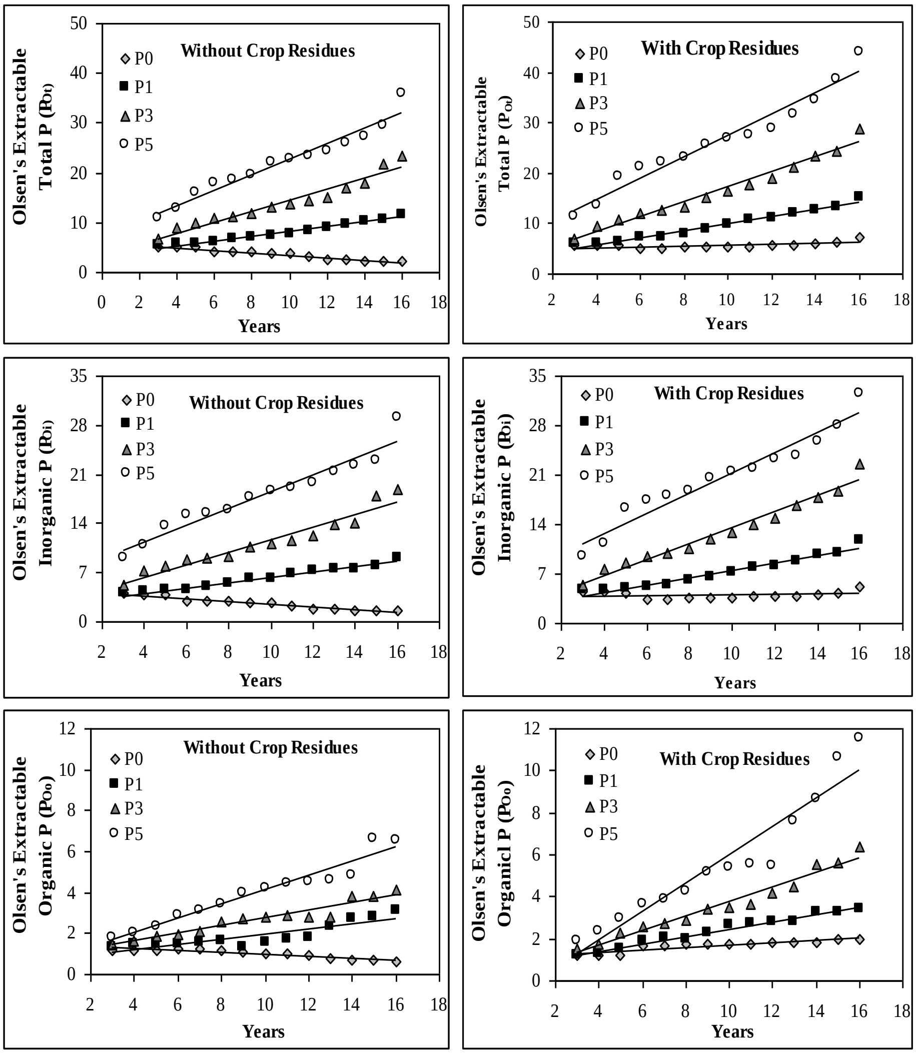
Table (6) presents the parameters of regression of Olsen's P forms over years. The slope of the regression line (x coefficient in the regression equation y = a + b*x, where y is the Olsen's P form and x is the year) measures the rate of changing of Olsen's P form over years. It is quite clear that the levels of Olsen's P forms were markedly reduced (negative correlation coefficient and negative slope values) because of neither addition of P fertilizer nor incorporation of crop residues. This means that in soil that received neither SP nor CR the initial levels of $P_{\mathbf{Ot}}$, $P_{\mathbf{Oi}}$, and $P_{\mathbf{Oo}}$ were yearly reduced by a rate of 0.26, 0.21 and 0.05 mg P kg^{-1} $year^{-1}$, respectively. These results confirmed the recent findings of Colomb *et al*. (2007) whose results emphasized that the Olsen P concentrations decreased gradually over the initial period 1969-1991, by -0.10 mg P kg^{-1} $year^{-1}$ ($r^2 = 0.78$) in the P_0 treatment.

With increasing the application level of SP, the slopes of the regression line increased. This means that the rate of increasing the level of Olsen's P forms was yearly increased with increasing the level of SP application. To show the importance of these trends, the following example can be cited. The total Olsen's P (P_{Ot}) increased by a rate of 0.47 mg P $kg^{-1}year^{-1}$ as a result of addition of 15.5 kg P_2O_5 fed^{-1} (P_1) per growth season each year to the soil that received no crop residues. While it increased by a rate of 1.55 mg P $kg^{-1}year^{-1}$ with increasing the application rate of P to 77.5 kg P_2O_5 fed^{-1} (P_5).

Table 6. Parameters of regression analysis of Olsen's extractable P over years as affected by P fertilization and application of crop residues.

Olsen's Extractable P ppm	**Levels of P Fertilizer**	**Without Crop Residues**			**With Crop Residues**		
		R	**Slope**	**Intercept**	**R**	**Slope**	**Intercept**
$\mathbf{P_{Ot}}$	$\mathbf{P_0}$	-0.99	-0.26	5.54	0.63	0.08	5.10
	$\mathbf{P_1}$	0.99	0.47	4.42	0.99	0.69	4.37
	$\mathbf{P_3}$	0.97	1.10	5.72	0.99	1.48	5.44
	$\mathbf{P_5}$	0.98	1.55	10.26	0.98	2.11	10.54
$\mathbf{P_{Oi}}$	$\mathbf{P_0}$	-0.97	-0.21	4.18	0.19	0.02	3.86
	$\mathbf{P_1}$	0.99	0.37	3.37	0.98	0.52	3.36
	$\mathbf{P_3}$	0.96	0.90	4.55	0.98	1.13	4.48
	$\mathbf{P_5}$	0.97	1.20	8.94	0.97	1.42	9.95
$\mathbf{P_{Oo}}$	$\mathbf{P_0}$	-0.90	-0.05	1.34	0.89	0.06	1.23
	$\mathbf{P_1}$	0.87	0.12	0.94	0.99	0.17	1.06
	$\mathbf{P_3}$	0.96	0.19	1.27	0.98	0.35	0.99
	$\mathbf{P_5}$	0.97	0.35	1.36	0.95	0.67	0.59

P_0= 0.00, P_1= 100, P_3= 300, P_5= 500 kg SP fed^{-1} for each growth season, r= Correlation coefficient



P0= 0.00, P1= 100, P3= 300, P5= 500 kg SP fed^{-1} for each growth season and CR= crop residues.

Fig. 2. Effects of long-term (16 years) application of P fertilizer (SP) and crop residues on Olsen's extractable P (mg kg^{-1})

With the incorporation of crop residues, this rate became as high as 0.69 mg P kg^{-1}year^{-1} with 15.5 kg P_2O_5 fed^{-1}, and even higher to reach a value of 2.11 mg P kg^{-1}year^{-1} with 77.5 kg P_2O_5 fed^{-1} each growth season. These relations could be used to predict the levels of Olsen's P forms in the studied soil at any time using different levels of P fertilization.

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استخدام الاضافات المستمره لبقايا المحاصيل والسماد الفوسفاتى لتحسين حالة الفوسفور فى التربة

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أجريت تجربة حقلية بمزرعة كلية الزراعة , جامعة اسيوط منذ عام 1988 حيث تم اتباع دورة زراعية لزراعة الذرة و البرسيم وذلك للحصول على برنامج إدارة موحد للتسميد الفوسفاتي مناسب لإنتاج المحاصيل ونوع التربة بهذه المزرعة التجريبية.

بعد الحصاد و قبل خلط بقايا المحاصيل بالتربة تم أخذ عينات التربة من كل القطع المنشقةمن الطبقة السطحية (0.00 – 0.25 م). أخذت من 3-5 عينات من كل حوض وتم خلطها لعمل عينة مركبة. تم تجهيز عينات التربة المأخوذة بعد كل موسم نمو حسب الطريقة القياسية ثم خزنت لإجراء التحليلات. وتم تقدير المادة العضوية و الفوسفور المستخلص بطريقة أولسن في كل العينات المأخوذة بعد حصاد الذرة.

أدت الإضافة المستمرة لبقايا المحاصيل لزيادة معنويه فى النسبة المئوية للمادة العضوية من 1.23% في سنة 1990 إلى 2.39% في سنة 2003 بينما حدثت زيادة طفيفة فى النسبة المئوية للمادة العضوية (من 1 الى 1.23 %) فى حالة عدم اضافة بقايا المحاصيل .

كان التغير فى صور الفوسفور المستخلص بأولسن خطى و معنوى مع الإضافات المستمرة من السوبر فوسفات و المادة العضوية وكانت التغيرات أكبر عندما أضيف السوبر فوسفات مع بقايا المحاصيل نتيجة لزيادة معدلات اضافة السماد الفوسفاتى الى 77.5 كجم P_2O_5 للفدان (سواء مع اضافة بقايا المحاصيل او بدون اضافة) ، زادت كمية الفوسفور الميسر حتى وصلت الى قيم قد تؤدى الى تلوث المياه الجوفية أو السطحية بالفوسفور .