5 *Egypt. J. Soil Sci.* **Vol. 53,** No. 1, pp. 55- 65 (2013)

The Feasibility of Using Unconventional Fertilizers on P Availability in Soil

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THE FEASIBILITY of using different untraditional P sources, *i.e.*, compost, ground animal bones, ground fish bones and the rock phosphate together with phosphorin inoculants (P-dissolving bacteria) on improving P availability in soil is the aim of this study. The results show that the overall values of $NaHCO_3$ extractable-P were significantly higher in the Typic Torripsamments soil treated with compost, besides the no-P-treatment (control soil) compared with the other P sources, whereas P-extractability remained statistically unchanged in the sandy loam soil under all treatments. Thus unconventional P-sources seemed to bring P in soils of poor P content to new levels of equilibrium. The results also reveal that P-extractability increased in the sandy loam soil during the incubation period in the form of consecutive peaks, each peak represents a case of significant increases in P extractability in soil followed by sudden reductions in extractable-P. Soils treated with animal bones, rock phosphate and fish bones recorded the highest increases in extractable P, while these treatments recorded the lowest values of extractable P at the beginning as well as at the end of peak relationships. On the other hand, the extractability of P changed in the Typic Torripsamments soil during the incubation period in the form of single peak.

The results confirm the importance of periodical inoculation of soil with phosphorin during the plant growth to improve P availability in soil and pointed up to the importance of rock phosphate, animal bones and fish bones as alternative sources for traditional or conventional fertilizers.

Keywords: Phosphate, Phosphorin, Unconventional P fertilizers, Bioavailability cycles, Phosphorus.

Superphosphates, either mono or triple, are among the important chemical fertilizers that have played important roles in the green revolution (Khan *et al.*, 2009) and their manufacture are based mainly on the available rock phosphate found in nature which is considered a non renewable source and is going forwards depletion within 50 to 100 years. Moreover, the qualities of the remained rock phosphate are low and the prices of the production of phosphate fertilizers are going up (Cordell *et al.*, 2009). Hence, the extensive use of chemical fertilizers during the last couple of decades created high stress on the limited natural

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resources (Embrandiri *et al*., 2012). Besides, soils are exposed to contamination with heavy metals which are found as impurities in the used fertilizers (Giuffréde López Camelo *et al*., 1997). Such complications led to search for new alternatives for the chemical fertilizers that can be environmentally safe.

No wonder that some soils contain high concentrations of total P and these amounts resulted from the successive amounts of applied phosphate fertilizers for years. However; these fertilizers were fixed shortly in soil after addition (Frossard *et al*., 2011). So P is found in these soils mainly in an unavailable form for the grown plants. Likewise, introducing high concentrations of P of low solubility to the soil system can enrich the total content of P in soil, while slightly affect the grown plants. Accordingly, inoculating soil with P-dissolving bacteria is recommended to improve the availability of P in soil to meet the plant needs. In this concern, many researches referred to the high efficiency of the bacterial inoculations with P-dissolving bacteria on improving the availability of P in soil (Zaidi *et al.*, 2009 and Kuhad *et al.*, 2011) .

Therefore, the current research was carried out aiming at studying the effects of treating soil with different alternative sources of P together with P-dissolving bacteria on improving P availability in soil at different time intervals.

Material and Methods

Soils of study

Two surface soil samples (0-30 cm) were collected from two different sites. The first one represented sandy loam soil collected from Shalaqan region, Kalybia Governorate while the other one is a virgin sandy soil collected from the Agricultural Research Station of the National Research Center at El-Nobaria, Bohera Governorate. These soils are Typic Torrifluvents and Typic Torripsamments, respectively. The studied soils were analyzed for their chemical and physical properties according to the standard methods outlined by Page *et al.* (1982) and Klute (1986). The results were shown in Table 1.

TABLE 1. Chemical and physical properties of the studied soil.

Site	Sand (%)	Silt (%)	Clay (%)	Textural class	$CaCO_3$ content, g kg^{-1}	OM content, g kg^{-1}	pH	EC dS m^{-1}	Available P mg kg^{-1}
Shalaqan	69.5	15.0	15.5	Sandy loam	2.4	5.0	7.6	0.8	15.9
El-Nobaria	88.5	8.0	3.5	Sand	3.6	0.6	7.7	0.8	3.9

Experimental procedure

A pot experiment, with three replicates for each treatment, was conducted as follows : soil portions of 200 g each were mixed thoroughly with different sources of P, *i.e.,* compost T_2 (4.6 g P kg^{-1}), ground animal bones T_3 (90.0 g P kg^{-1}), rock phosphate T_4 (122.0g P kg^{-1}) and ground fish bones T_5 (72.1g P kg^{-1}) to keep the total content of added P in all treatments equal to 135.0 mg P kg^{-1}, beside of the no P-treatment, *i.e.*, the control treatment (T_1). Soils were then uniformly packed in plastic pots (6 cm diameter × 9 cm depth). Phosphorin inoculant (P-dissolving bacteria) was added to all pots through water applications and each pot received deionized water to bring soil moisture at field capacity. The soil moisture was maintained gravimetrically at this moisture content throughout the incubation periods. Soils in the pots were sampled at time periods of 1 hr (zero time), 7, 15, 21, 28, 35, 42 and 48 days after incubation. A vailable P was extracted by 0.5 M $NaHCO_3$ (pH 8.5) and determined using the ascorbic acid method (Page *et al*., 1982) and measured colormetrically with spectrophotometer model Jenway 6300 UK.

Data analysis

Extractable-P data were statistically analyzed using the Minitab program through analysis of variance (ANOVA) and least significant difference (LSD) at 0.05 probability level. P retention in Typic Torripsamments soil was calculated as outlined by Abbas and Salem (2011) as the highest concentrations of available P (peak apex) were taken as the concentrations of AB-DTPA extractable-P obtained at zero time of incubation and the consecutive values obtained afterwards were subtracted from the P-concentration obtained at the zero time. P-retention data were plotted graphically against the time of contact and the retention relations were fitted using 6 kinetic models to explore the mechanism or mechanisms that might affect P-retention in soil (Table 2).

TABLE 2. The kinetic models used in this study.

Kinetic equation	Parameters	Reference
Zero Order: $Q_t = Q_0 - k_0 t$	k_0, Zero order rate constant $(\mu g P.g^{-1} h^{-1})$	Wolt (1994)
First Order: $\ln Q_t = \ln Q_0 - k_1 t$	k_1, first-order rate constant (h^{-1})	Wolt (1994)
Second Order: $1/Q_t = 1/Q_0 - k_2 t$	k_2, second-order rate constant $(\mu g P.g^{-1})^{-1}$	Wolt (1994)
Simple Elovich: $Q_t = 1/\beta \ln(\alpha\beta) + (1/\beta) \ln t$	α, initial sorption rate $(\mu g P.g^{-1} h^{-1})$ β, sorption rate constant $(\mu g.P.g^{-1})^{-1}$	Dang *et al*. (1994)
Power function: $Q_t = at^b$	a, initial sorption rate constant $(\mu g.P.g^{-1} h^{-1})^b$ b, sorption rate coefficient $(\mu g P.g^{-1})^{-1}$	Dang *et al*. (1994)
Parabolic diffusion $Q_t = Q_0 + K_p t^{1/2}$	k_p, diffusion rate constant $(\mu g P.g^{-1})^{0.5}$	Reyhanitabar *et al*. (2011)

Q_0 and Q_t refer to the concentrations of adsorbed P (μg g-1) calculated at zero time and "t" time (hour), respectively. Also, the standard error of estimate (S.E.) for each of the kinetic model was calculated according to Shariatmadari (2006) as follows:

$$SE = [\sum (Q_t - Q_t{}')^2 / (n-2)]^{1/2}$$

Q_t and $Q_t{}'$ are the measured and predicted amounts of the adsorbed-P obtained at time t, respectively, and n is the number of measurements.

Results and Discussion

P –extractability from soil as affected by applying different sources of P and the time of soil contact

The results illustrated in Fig. 1-A show that the concentrations of the extractable-P increased significantly in the Typic Torripsamments soil amended with compost (T_2) compared with the control (T_1). It is well known that the compost enriches soil with P during its decomposition on the short and long run (Jalali and Ranjbar, 2009). On the other hand, the concentrations of extractable-P decreased significantly in soils treated with either animal bones (T_3), rock phosphate (T_4) or fish bones (T_5). These results indicate that these amendments (T_3, T_4 and T_5) brought soil P to new levels in P equilibrium in soil. In other words, these amendments have lower solubility product than minerals found originally in soil (responsible for P solubility) and therefore, introducing these amendments to soil system reduced the solubility of P in soil and thus its extractability with $NaHCO_3$. On the other hand, no significant effects were detected in P extractability in the sandy loam soil among the different P-sources. This might be because of the higher soil retention for P which exceeding the effect of the applied different P-sources. Thus, it can be deduce that P- retention could mostly increase with the increase in sand content in soil, and this reason might somehow explain the significant changes in P-extractability between the two soils. The obtained results agree, to some extent, with those of Perez et al. (2009) who found in a pot experiment that amending soil with either rock phosphate or meat-bones as P sources caused no significant changes in P bio-availability on the short run. The results highlight the effects of introducing either bones or rock phosphate to the soil system on reducing P availability on the short run. It is therefore important to clear out the effect of time on the availability of P in soil treated with different P-sources.

Concerning the effect of the incubation periods on P-availability, Fig. 1-B show that P extractability decreased significantly in the Typic Torripsamments and Typic Torrifluvents soils within the first 10 days of incubation and then increased significantly between the 10^{th} day (240 hr) and the 20^{th} days (480 hr) after incubation. Afterwards the behavior of P availability seemed to be completely different in the two studied soils. The extractability of P decreased gradually in the Typic Torripsamments soil after the 20th day of incubation, but the extractability of P in the sandy loam soil took the form of interval increases forming another peaks. The decreases in P availability in soil achieved at the tenth day of incubation indicates that the solubility of P in soil is readjusted to a new equilibrium level in soil and this result confirms our previous explanation for the application of rock phosphate, ground animal and fish bones. Afterwards, the phosphorin inoculants seemed to be more efficient in improving P solubility in soil until the 20th day after incubation (480 hr). It is more likely that soil components have high affinity for P retention (Cucarella and Renman, 2009), *i.e.,* sorption on hydroxy-inter-layered minerals (Karathanasis and Shumarker, 2009) and soil sediments (Wang and Li, 2010).

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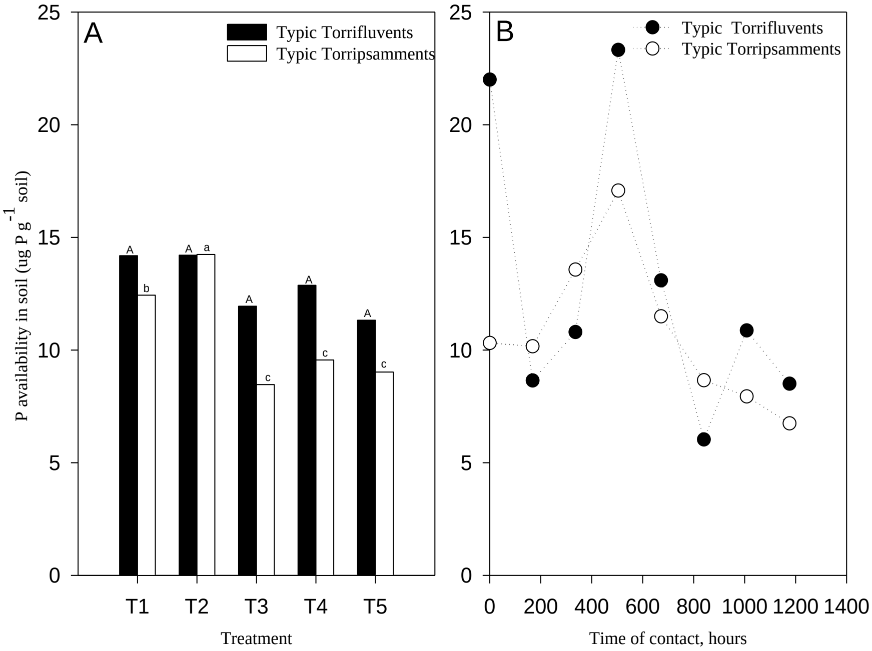

Fig 1. Extractable P in soil as affected by the application of different P-sources (A) and period of incubation (B).

Availability of P in the Typic Torripsamments soil as affected by the different treatments

The results shown in Fig. 2A reveal that P extractability in the soil increased due to all the treatments with the increase in the incubation period and reached its maximum values after 500 hr, except for the control treatment, and decreased afterwards. P availability reached its maximum values in the control treatment after 360 hr. The recorded reductions in the availability of P in all treatments seemed to be steady until the end of the incubation period and such reductions were defined by P retention in soil.

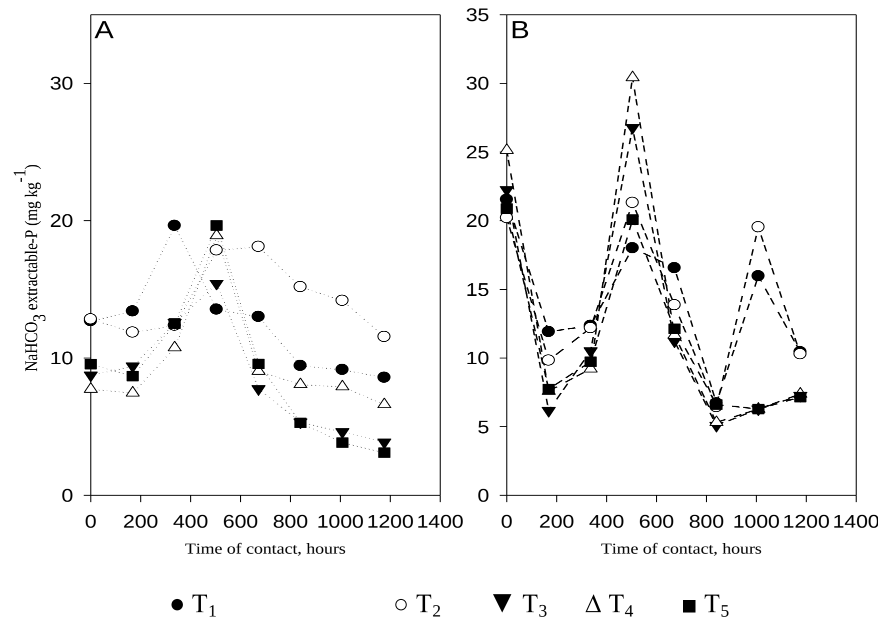

Fig. 2. Effect of the time of contact on P extractability in Typic Torripsamments (A) and Typic Torrifluvents (B) amended with phosphorin and different P sources.

The calculated P-retention data were plotted graphically against the time of contact in hours and the relations were fitted using 6 kinetic models to determine the mechanism that might affect P-retention in soil (Fig. 3). The calculated parameters of the different kinetic models were illustrated in Table 3.

TABLE 3. The calculated parameters of the fitted kinetic models in Typic Torripsamments soil.

	Zero order		**First order**		**Second order**		**Simple Elovich**		**Power function**		**Parabolic diffusion**	
	S.E.	**r^2**	**S.E.**	**r^2**	**S.E.**	**r^2**	**S.E.**	**r^2**	**S.E.**	**r^2**	**S.E.**	**r^2**
T_1	0.548	0.957	0.394	0.876	0.787	0.620	0.369	0.971	0.238	0.925	0.434	0.966
T_2	0.844	0.927	0.009	0.990	0.003	0.974	1.358	0.873	0.022	0.974	1.086	0.907
T_3	0.850	0.900	0.013	0.868	<0.001	0.790	0.503	0.941	0.008	0.915	0.666	0.924
T_4	0.217	0.927	0.0128	0.868	0.001	0.900*	0.272	0.909	0.008	0.915	0.241	0.919
T_5	3.397	0.865	0.026	0.827	<0.001	0.936	2.129	0.915	0.018	0.884	2.733	0.891

Control T_1, compost T_2, animal bones T_3, rock phosphate T_4, fish bones T_5 .

According to the highest "r^2" and the least "S.E." values, simple Elovich kinetic equation seemed to be the best kinetic model for fitting P-retention for most treatments in the studied Typic Torripsamments soil. Such a result agree with those obtained by Chien and Clayton (1979), Torrent (1986) and Cheung & Venkitachalam (2006) who found that P-sorption kinetic data best fitted Elovich model.

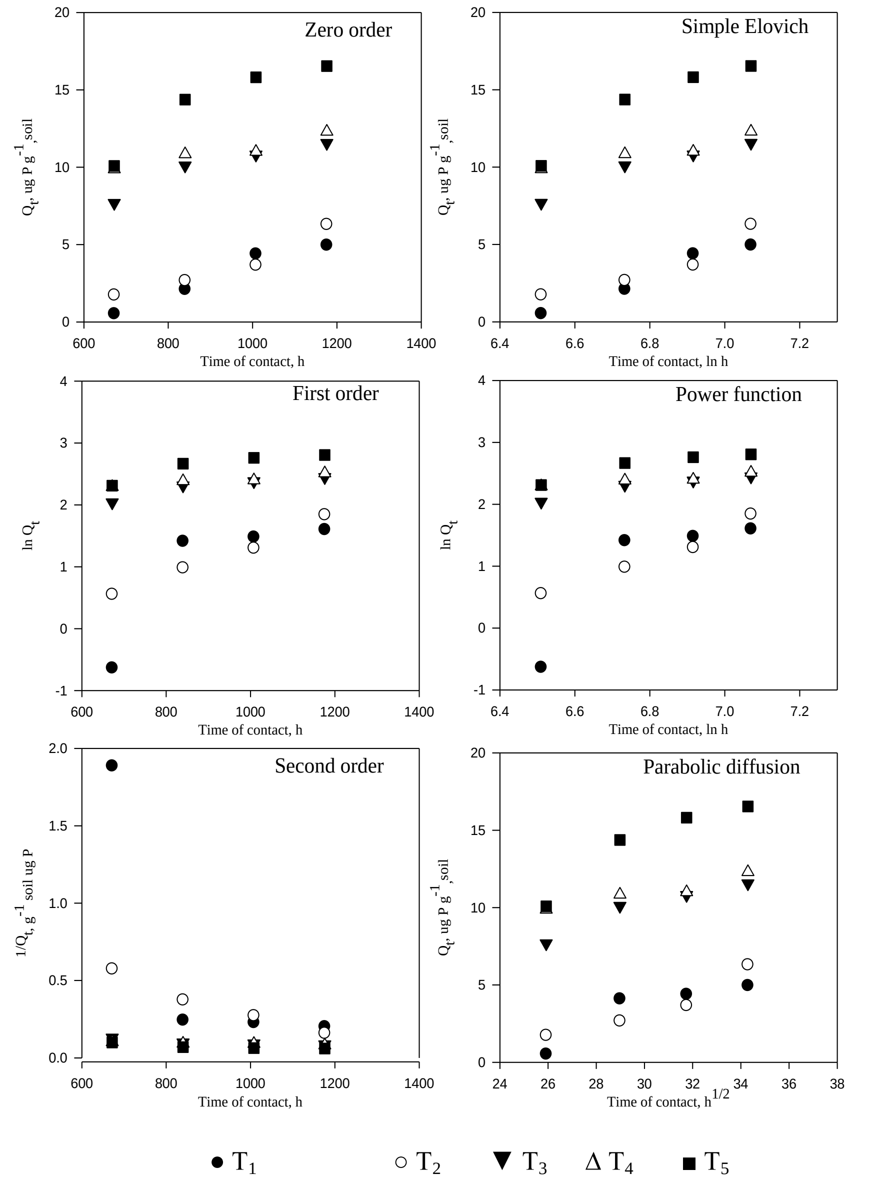

Fig. 3. Fitting the retention data of P in Typic Torripsamments soil to the different kinetic models.

Availability of P in sandy loam soil as affected by phosphorin inoculation and the different treatments

The results shown previously in Fig. 2-B reveal that the extractability of P in the sandy loam soil increased in the form of consecutive peaks with increasing the time of the incubation period. Each peak represents a case of significant increases in the extractability of P in soil, followed by sudden reduction in P availability. It is very surprising to find that soils amended with animal bones (T_3), rock phosphate (T_4) and fish bones (T_5) recorded the highest increases in $NaHCO_3$ extractable-P after 500 h of incubation, while these treatments recorded the lowest values of $NaHCO_3$ extractable-P at both the beginning and end of peak relationships, *i.e.,* 200 hr and 800 hr , respectively. Also, these three amendments showed slight steady increases in the extractable-P after 800 hr, while the increases which were recorded for the control soil and for the soil amended with organic matter were more pronounced and took the mostly the form of second peak . Accordingly, we assume that the increases obtained owing to T_3, T_4 and T_5 treatments which were attained after 800 hr of incubation were mostly beginnings for the other cycle of increases and declines in P-extractability in soil, however these peaks might take much longer time to develop. One possible explanation is that the nutrient level in the sandy loam soil was relatively high compared with the sandy soil and therefore stimulated further microbial activity for improving P-availability in soil. Thus, the levels of $NaHCO_3$ extractable P attained at the tenth day of incubation were much higher in the sandy loam soil than in the Typic Torripsamments soil. On the other hand, a kind of competition might occur between the microbial populations on soil nutrients in sandy loam soil, accompanied by minimizing the populations of the P-solubilizing microbes; accordingly P-retention in soil was more noticeable during this period. Hence, the released nutrients from the catabolism of the bodies of the dead microbes might lead to re-stimulation for the remained P-solubilizing bacteria and, therefore, started new peaks of stimulating P bio-availability in the sandy loam soil, which would have much lower P-extractable levels than those recorded in the first peaks.

It is worthy to mention that P-availability in the studied sandy loam soil took the form of consecutive cycles rather than steady state form and therefore studying the kinetics of P in this soil is very difficult because every single value is a resultant of two opposite effects which are the increases in P extractability due to the phosphorin inoculant activity and decreases in P extractability owing to the retention of P by soil components.

Conclusion

P extractability from the Typic Torripsamments soil increased due to all treatments and the increase became more pronounced by increasing the incubation period up to 500 hr (for all the treatments except for the control one) where it reached its maximum value, thereafter decreased. P availability reached its maximum values in the control treatment after 360 hr and decreased afterwards. The recorded reductions in the availability of P in all treatments seemed to be steady until the end of the incubation period and such reductions were defined by P retention in soil. On the other hand, P-availability in the studied sandy loam soil took the form of consecutive cycles rather than steady state form. Each peak represents a case of significant increases in the availability of P in soil, followed by sudden reduction in P availability. Accordingly, our results confirm the importance of periodical inoculation of soil with phosphorin during the plant growth to improve P-availability in soil and pointed up to the importance of animal bones, fish bones and rock phosphate as alternative sources for the superphosphate fertilizers; however, further researches are required to provide continuity for the increases in P availability rather than increasing P availability in the form of consecutive peaks.

Acknowledgement : The authors would like to express their thanks to Prof. Dr. Omar A. El-Hady (Soils and Water Use Dept., National Research Center, Cairo) for his profitable advices during preparing the manuscript.

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(*Received* 19/12/2012;
accepted 3 / 3 / 2013)

جدوى استخدام مصادر غير تقليدية للفوسفور علي تيسره فـــي التـــربـــة

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تهدف الدراسة إلى معرفة جدوى استخدام مصادر غير تقليدية للفوسفور على رفع مستوى تيسر الفوسفور فى نوعين من التربة (تربة رملية وتربة رملية طميية) وهذه المصادر تتمثل فى : الكمبوست ومسحوق كل من عظام الحيوانات وعظام الأسماك والصخر الفوسفاتى، وقد أوضحت الدراسة ما يلى :

1. حدوث زيادة معنوية فى الفوسفور المستخلص من التربة الرملية بطريقة أولسن (بيكربونات الصوديوم 0.5 مولر pH 8.5) مقترنا بمعاملة التربة بالكمبوست، بالإضافة إلى معاملة الكنترول مقارنة بالأرض المعاملة بأى من عظام الحيوانات، عظام الأسماك أو الصخر الفوسفاتى والتى يبدو أن هذه المصادر غير التقليدية قد دفعت الفوسفور إلى مستوى جديد من الاتزان ، فى حين لم تظهر أى تأثير معنوى للمعاملات على الفوسفور المستخلص بطريقة أولسن فى الأراضى الرملية الطميية.

2. الفوسفور المستخلص من الأرض الرملية الطميية جاء على شكل دورات متعاقبة من زيادات معنوية فى الفوسفور المستخلص من التربة يتبعه انخفاضات فى الفوسفور المستخلص ، حيث سجلت أعلى زيادات وأقل انخفاضات فى منحنيات تيسر الفوسفور قد تم التحصل عليها فى الأراضى المعاملة بعظام الحيوانات، الصخر الفوسفاتى وعظام الأسماك وعلى الجانب الأخر اتخذ الفوسفورالمستخلص من الأرض الرملية شكل دورة وحيدة من الزيادة والانخفاض.

3. تؤكد الدراسة على أهمية التلقيح الدورى للتربة بواسطة لقاح الفوسفورين (كبكتريا مذيبة للفوسفات) خلال فترات نمو النبات لتحسين حالة تيسر الفوسفور فى التربة ، كما اشارت إلى أهمية استخدام عظام الحيوانات والاسماك بجانب الصخر الفوسفاتى كمصادر غير تقليدية للاسمدة الفوسفاتية.