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Water Flow Through Saturated Clay Soil and Moisture Tension Relations as Affected by Ca-monobasic Phosphate Treatment

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ABSTRACT

The effect of Ca-monobasic phosphate addition to clay soil on the rate of water flow and moisture tension relations was examined under controlled laboratory experiment. The ca-monobasic phosphate was added to soil in two different rates, namely 0.05%, and 0.1% on weight basis. It was found that the addition of ca-monobasic phosphate changed slightly both the percent total pore space and pore size distribution. The data indicate that the change in moisture tension relation between treated and untreated soil was negligable. In the saturated water flow study it was found that the flow through the clay soil obtained from El Marj area did not follow the linear relationship of Darcy's law. It was found that the saturated hydraulic conductivity value increased with higher applied hydraulic gradient. It was also observed that the flow through that clay soil could be described by the equation

$$V = \left[0.86i + 0.228i^2\right]10^{-2}$$

where V is the flux in cm/hr and i is the hydraulic gradient. When ca-monobasic phosphate was added to the clay soil the pattern of flow was changed in two ways. First the flow in treated soil obeyed Darcy's law linear relationship. The second effect was that the saturated hydraulic conductivity (K) decreased. For example in comparison with the untreated soil, there was 12% reduction in the value of K for the 0.05% treatment, while this reduction was 34% in the 0.1% treatment. This behaviour could be explained on the basis of possible reaction which affected the stability of porous material and passage of water in soil pores.

INTRODUCTION

The reaction between the soil and added phosphate has been studied by soil chemists (3,8). Cole *et al.* (6) demonstrated that phosphate was fixed by crystals of calcium carbonate in calcarious soil, and they concluded that the reaction was not a chemical reaction but an adsorption phenomenon. Asseed *et al.* (2) found that addition of ca-monbasic phosphate to calcarious soil reduced both total pore space and the size of the individual pores in soil, and consequently the rate of saturated flow was reduced. The objective of this experiment was to determine the effect of addition of ca-monobasic pohsphate on porosity, moisture retention, and rate of water flow of clay soil with 0.7% $CaCO_3$ and 1% free extractable iron.

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MATERIALS AND METHODS

Soil from the surface 0–30 cm of the soil profile of El Gharig area in El Marj was used in this study. The soil is clay in texture and its physical and chemical characteristics is shown in Table 1. After collecting the soil it was spread and allowed to dry in the air. The soil was then seived through a 2 mm seive and mixed for homogeniety. Calcium-monobasic phosphate was added to the aoil at two different rates, namely 0.05% and 0.1% on weight basis. For the moisture tension relationship study pressure chambers with porous plates were used. Soil samples were packed in metal cylinders 7.6 cm in diameters and 6.5 cm in height. The packing bulk density was 1.3 g/cm³ for all treatments. The soil samples on the porous plates were saturated by soaking in water and were allowed to stand for three weeks before pressure was applied on them. Different pressure increments were applied and the total volume of water removed from the soil as a result of the application of the pressure increment was measured. For the saturated flow study, samples were packed in plexiglass tubes 25 cm long and 6 cm in diameter at a bulk density equal to 1.3 gm/cm³. To obtain uniform packing the tubes were divided into 5 cm sections and equal masses of soil were packed in equal volumes in the plexiglass tubes. The soil columns were saturated with distilled deaerated water and left for 3 weeks period. Then the soil columns were connected to flow meters with constant head device to control the hydraulic head applied. Different hydraulic gradients were applied to the soil columns and velocity was measured at each hydraulic gradient.

RESULTS AND DISCUSSION

Figures 1 to 3 show the relationship between the water present in the soil and the energy with which it was held for untreated soil and soils treated with different amounts of ca-monobasic phosphate. At zero tension the percent moisture on volume basis for the untreated soil was 48%, while it was 50% for soils treated with both 0.05% and 0.1% phosphate. This indicates a slight increase in percent total pore space in treated soil compared to the untreated soil.

Generally speaking the moisture retained at any given tension higher than zero was approximately the same for both the untreated and treated soils.

Table 2 shows the pore size distribution for both the untreated and treated soils. The pore size distribution data was obtained from curves relating water content and tension by the equation

$$r = \frac{2\sigma}{heg}$$

where r is the upper limiting radius of pores which can remain full of water when a tension of h cm of water is applied to the water in the wet soil, σ is the surface tension coefficient, e is the density of water and g is the acceleration of gravity. The size distribution of the pores in the soil provides a specification of its structure. The data show that the application of ca-monobasic phosphate did not meaningfully affect the pore size distribution in the soil. For example the volume of pores which have size between 0–3 micron in diameter is 25.0 cm³/cm³ (volume of pores related to bulk volume of soil) in the untreated soil, while it was 24.7, and 24.5 cm³/cm³ in soil treated with 0.05% and 0.1% phosphate respectively (approximately a change of 2% for the 0.1% treatment compared to the untreated soil).

Table 1 Physio-chemical characteristics of the soil.

Location	Depth	Mechanical composition			TSS %	pH 1:25 H_2O	$CaCO_3$ %	Free iron oxides %	Cations and Anions in 1:5 extract meq/100 soil							
		Clay	Silt	Sand					CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K
El-Gharik El Marj	0–30	56.8	30.8	12.4	.03	7.3	0.7	1 (one)	Nil	0.28	0.24	0.30	0.21	0.08	0.48	0.05

Table 2 Pore size distribution of clay soil treated with different amounts of Ca-monobasic phosphate (Volume of pores are expressed as percentage of bulk volume of soil).

Treatment	Size range (diameter in μ)									
	0–3	3–5	5–6	6–7.5	7.5–10	10–15	15–20	20–30	30–60	60–120
Untreated soil	25.	6	1.6	1.4	1.8	3.7	2.3	2.8	2.2	1.7
Soil treated with 0.05% Ca-monobasic phosphate	24.7	6.8	1.7	1.6	2.0	3.8	2.2	2.7	2.6	2.4
Soil treated with 0.1% Ca-monobasic phosphate	24.5	6.8	1.6	1.6	2.1	3.8	1.9	2.7	2.5	2.4

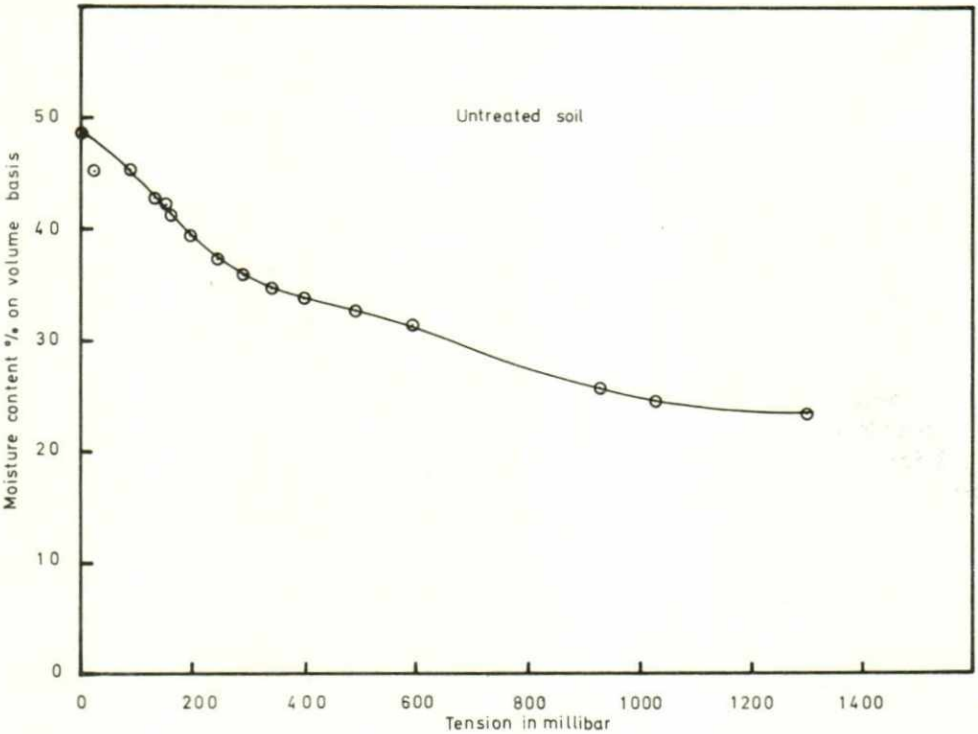

Fig. 1. Soil water energy relationship for untreated soil.

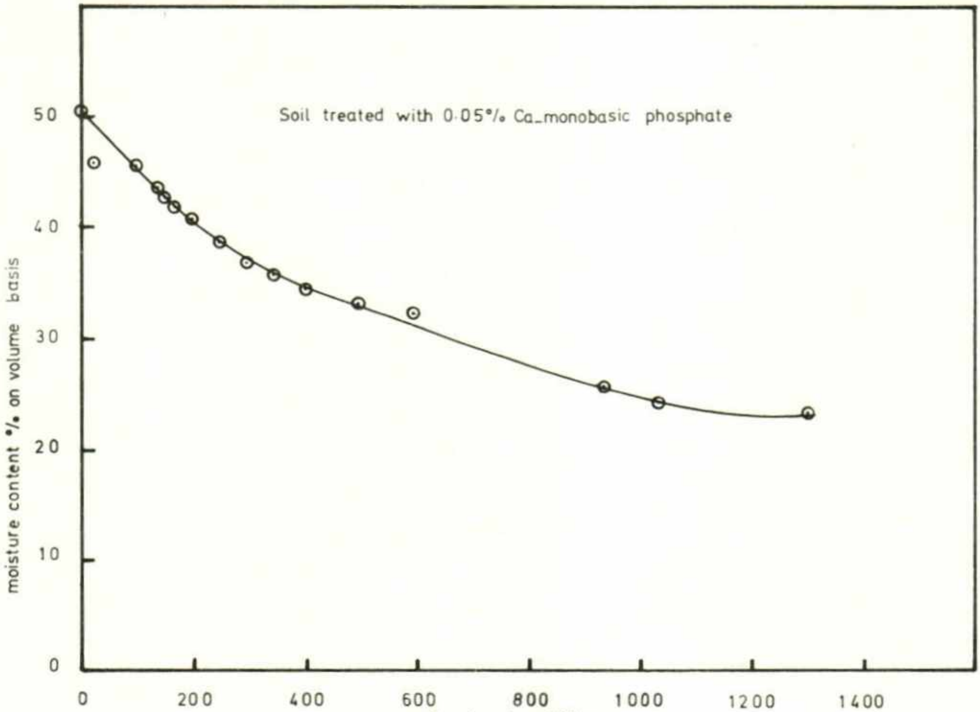

Fig. 2. Soil water energy relationship for soil treated with 0.05% Ca-monobasic phosphate.

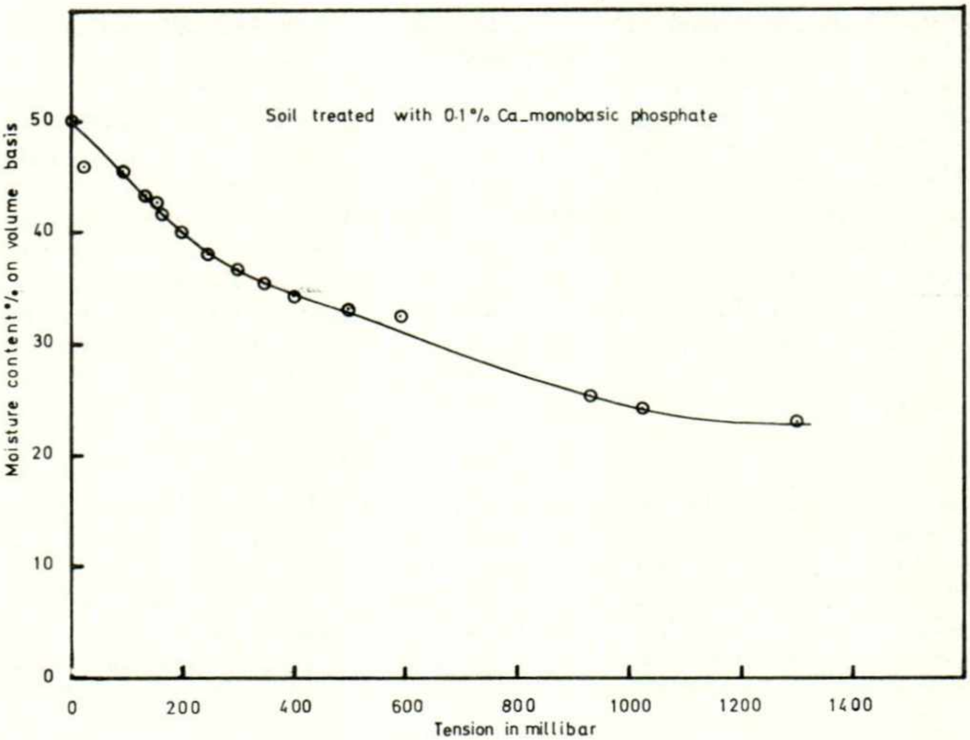

Fig. 3. Soil water energy relationship for soil treated with 0.1% Ca-monobasic phosphate.

Figure 4 shows the velocity of flow versus hydraulic gradient in the untreated soil. The graph shows that the flux versus hydraulic gradient does not follow the straight line relationship assumed in Darcy's law which describes the flow as

$$V = Ki$$

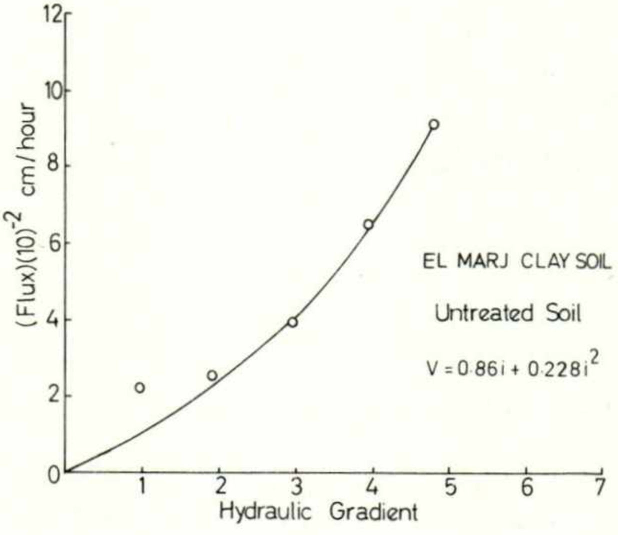

Fig. 4. Water flux versus hydraulic gradient for El Marj clay soil (untreated).

where V is the flux in saturated porous media and soil, i is the hydraulic gradient, and K is the saturated hydraulic conductivity which is taken as constant for a given porous medium under isothermal condition. The data for the clay soil indicate non-Darcy behaviour since the flux versus hydraulic gradient does not follow the straight line relationship. In another word saturated hydraulic conductivity (K) in the clay soil is not the same at each hydraulic gradient. Similar findings were obtained by Russell *et al.* (14). It is clear that at low hydraulic gradient K has a smaller value compared with its value at higher gradient. For example $K = (1.1)(10^{-2})$ cm/hr when hydraulic gradient $i = 1$ while its value is $(1.63)(10^{-2})$ cm/hr when $i = 4$ (a change of 53%). Trials were held to fit the flow data of that clay untreated soil to an empirical equation and the result is shown in Figure 5, in which v/i is plotted versus i, and a straight line relationship is obtained. So the flow equation for the clay soil from El Marj area was found to be

$$V = \left[0.86i + 0.228i^2\right] 10^{-2}$$

The other finding from Figure 4 is that the rate of flow in that clay soil is very slow and it could be classified as essentially impermeable, and reclamation of that soil should be aimed to increasing the rate of water movement in that soil.

The effect of addition of ca-monobasic phosphate to clay soil on water flow is shown in Figures 6 and 7 where the flux is plotted versus hydraulic gradient. It is interesting to note that addition of ca-monobasic phosphate affected the saturated flow in two

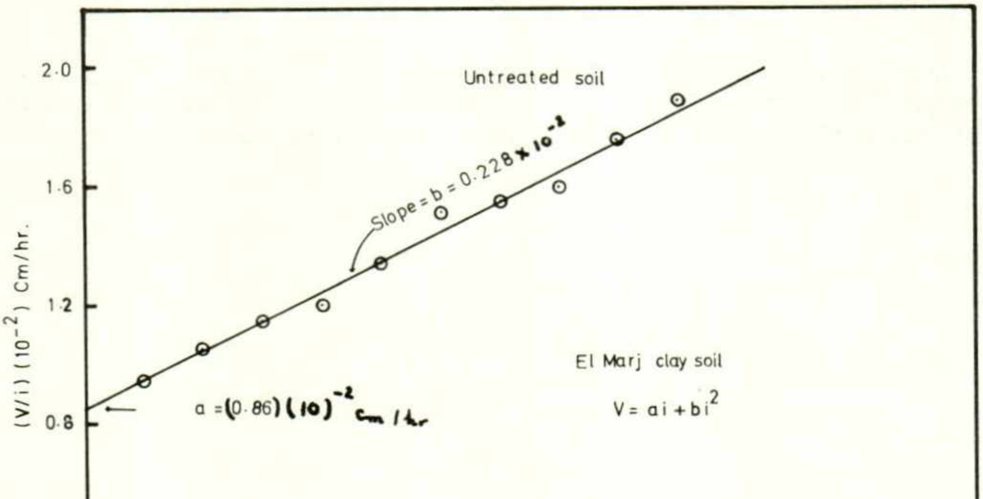

Fig. 5. [Water flux/hydraulic gradient]: versus hydraulic gradient for El Marj clay soil (untreated).

ways. First the flow in the treated soil follow the straight line relationship of Darcy's law, while in the untreated soil as was discussed before the flow did not obey Darcy's law. The reason for that behaviour is not known especially the data on porosity and pore size distribution does not indicate any meaningful variation due to ca-monobasic phosphate application. It could be explained on the basis that addition of phosphate resulted in some reaction which affected the arrangement and stability of clay particles such that the soil behaved with a constant value of saturated hydraulic conductivity regardless of the applied hydraulic gradient. The ca-phosphate possible reacted with iron in micro-climate space (reaction) leads to the formation of amorphorous iron phosphate, since these soils have about 1% dithonite extractable irons.

The second effect of the phosphate treatment is the reduction of the value of saturated hydraulic conductivity (K) compared to the untreat soil. It was found that $K = (1.27)(10)^{-2}$ cm/hr for the 0.05% phosphate treatment, while its value was $(0.95)(10)^{-2}$ cm/hr for the 0.1% treatment. Comparing these values with the average K value for the untreated soil revealed that there was 12% reduction in the value of K in the 0.05% phosphate treatment, while the reduction amounted to 34% in the 0.1% treatment. This behaviour could be explained on the basis of some possible reactions which affected the passage of water in the pores.

Formation of octocalcium phosphate ($Ca_8H_2(PO_4)_6 \cdot 5H_2O$, and Hydroxy apatite as a result of the transformation of calcium monobasic phosphate. About 30 ppm of P added as calcium monobasic phosphate shaked for 4 hours only 6 ppm of P extracted by Olsen Method).

Formation of iron phosphate. Since these soil contains 1% sodium dithionite ($Na_2S_2O_4$) extractable iron. (Olsen 1965).

$$M^{+3} + H_2PO_4^- + {}_2H_2O = M(OH)_2H_2PO_4 + 2H^+.$$

Here this reaction in this cause possible only at the vicinity of fertilizer particles, due to localized high acidity and high phosphate concentration (Hsu. 1964, 1960), also reported similar reactions but also we think the phosphate will be adsorbed by amorphous aluminium hydroxides and iron hydroxides in this case. Change and Jackson (1958) found that in the majority of calcerous soils P is present as a calcium phosphate although some can exist in the aluminium and iron fractions, also they believed when phosphate fertilizers are added to calcereous soils P can bind with calcium and aluminum and not with iron because these ions are more active.

Inert phosphate, apatites and non apatitic calcium phosphate fractions accounted for most of the inorganic fraction when expressed as a percentage of the total soil P. Sen Gupta and Cornfield (1962) reported these and also indicated in the presence of calcium carbonate non apatitic forms are slowly converted to apatitic forms.

These soils also relatively has a high potassium concentration in their soil solution. Lindsay and Stephenson (1959) reported potassium tarankite and a possibly a partially substituted aluminum-iron phosphates resulted from action of solution derived from monobasic calcium phosphate.

The other mechanisms and reaction, that are responsible for changing the pores size and geometery of this soil is the phosphate sorption on several surface that are available in this soil. These surface include the oxides and hydroxides of Fe, Al, minerals and $CaCO_3$. Also the exchangeable Ca, Mg on the exchange sites of the clay minerals, any how, whether P removal from solutions in a given system is accomplished by a sorption or a precipitation, reaction is a function of P concentration in solution; kinetics, pH, type of a sorping material and some other physical and chemical soil

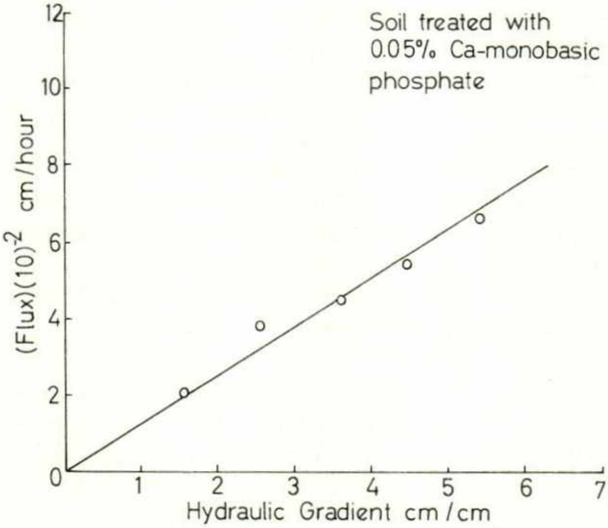

Fig. 6. Water flux versus hydraulic gradient for clay soil treated with 0.05% Ca-monobasic phosphate.

properties. Several investigators have reported the removal of orthophosphate from solution by (Wild 1950, 1964) Blanchet (1959) solid Fe and Al hydroxides. The amount of phosphate sorbed in these reactions varies with temperature, time of reactions, phosphate, concentration and pH of the solution. Formation of a separate phosphate

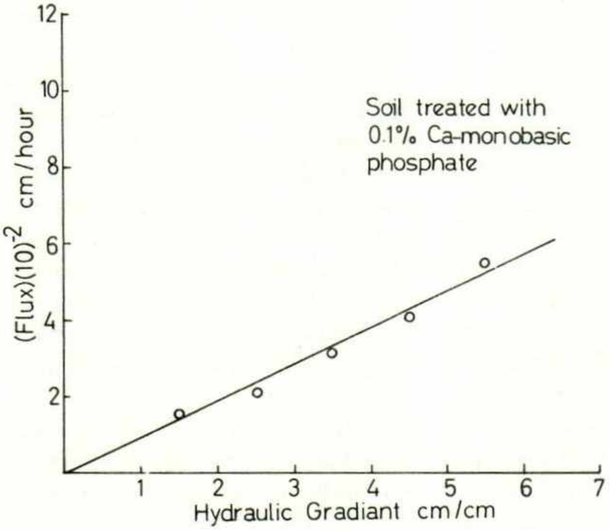

Fig. 7. Water flux versus hydraulic gradient for clay soil treated with 0.1% Ca-monobasic phosphate.

phases controlled by a solubility product principles which provided a unified theory of phosphate fixation. Dalal and Hallsworth (1977) found phosphate adsorption are more associated with aluminum and iron content respectively.

Rearrangement of adsorbed P or hydroxy of iron and aluminium on the surface of the kaolinite, smectite and interstratified glauconite minerals of these soils. The last reaction which we think the cause of change in pore size and geometery of these soils are (a) initial chemical sorption of P (b) physical adsorption perhaps multi-layer on the chemisorbed monolayer (3) precipitation of octocalcium phosphate from solution and its deposition on the adsorbed layers.

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حركة الماء خلال التربة الطينية المشبعة
بالماء والمعاملة بمركب فوسفور الكالسيوم الاحادى

محمد شعبان ـ الجيلانى عبد الجواد ـ احمد شعبان

المستخلص

فى هذا البحث تم دراسة تأثير اضافة فوسفور الكالسيوم الاحادى على حركة الماء فى التربة الطينية القوام من منطقة الغريق بالمرج ووجد بان : ـ

١ ـ اضافة فوسفور الكالسيوم الاحادى غير من توزيع حبيبات التربة والفراغ الحبيبى بعد ثلاثة أسابيع .

٢ ـ انخفض التوصيل الهيدروليكى للتربة نتيجة المعاملة وكذلك انطبق قانون دارسى للتوصيل الهيدروليكى على عكس التربة الغير معاملة .

٣ ـ سبب التغيير الذى استنبط من واحد واثنين هو التفاعل الكيميائى لمركب فوسفور الكالسيوم الاحادى مثثل : ـ

أ ـ تحويله الى مركب فوسفات الكالسيوم الثمانى نتيجة التفاعل مع كربونات الكالسيوم .
ب ـ تحويله الى فوسفات الحديد والالمونيوم فى المناطق المحيطة بحبيبات المركب نتيجة لدرجة الحموضة المنخفضة .

جـ ـ ادمصاص هذا المركب على سطوح المعادن الموجودة فى الجزئيات الطينية بهذه التربة .
بصفة عامة تربة هذه المنطقة ذات نفاذية منخفضة جدا ...