EFFECT OF PHYSICAL AND CHEMICAL PROPERTIES OF NORMAL SOILS ON HYDRAULIC CONDUCTIVITY VALUES AS MEASURED BY DIFFERENT METHODS

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ABSTRACT

Four soil profiles representing normal soils(non-saline non-sodic) were taken at Byalla district (Kafr El-Sheikh governorate) to study the relationship between physical and chemical properties of the soil and values of hydraulic conductivity as determined by three different methods (constant head, falling head and auger hole). Simple and multiple linear regression relationships were conducted between values of saturated hydraulic conductivity (Ks) and the different physical and chemical properties of the soil .The important results could be summarized as follows:

1- Ks as measured by constant head was affected by aggregation conditions and showed a highly significant positive correlation with each of water stable aggregates >0.25 mm (R^2 = 0.6814**) , aggregation index (R^2 = 0.6383**) and mean weight diameter (R^2 = 0.6439**). A highly significant positive correlation was found between Ks and both soluble Ca^{++}(R^2 =0.6309**) and exchangeable Mg (R^2 =0.5577**). Multiple linear regression between the above- mentioned chemical properties of the soil and Ks showed a significant correlation coefficient (R^2=0.9340*). It is obvious that soluble Ca^{++} is the most effective chemical parameter which affect Ks .

2- Ks determined by falling head method was greatly affected by aggregation parameters and has a highly positive correlation with both water stable aggregates >0.25 mm (R^2=0.6384**) and structure coefficient SC (R^2=0.7409**). A highly negative correlation was found between water conductivity and soil bulk density (R^2 = 0.7671**). The multiple linear regression between the abovementioned physical properties and Ks revealed a significant correlation (R^2=0.9250*). Ks by falling head method was also affected by the chemical properties of the soil. A highly positive correlation was found between values of hydraulic conductivity and each of exchangeable Mg (R^2=0.9114**), cation exchangeable capacity (R^2=0.7074**), calcium carbonate content (R^2=0.8106**) and organic mater content (R^2=0.7354**). Multiple linear regression between (Ks) and the chemical properties of the investigated soils showed a significant correlation coefficient (R^2=0.999*).

3- Statistical analysis showed no significant correlation between the values of saturated hydraulic conductivity which obtained by both constant head and falling head methods, and by the auger-hole method .

Key words: Hydraulic conductivity, constant head , falling head, auger hole, normal soils, non- saline non-sodic soils , physical and chemical properties

INTRODUCTION

Hydraulic conductivity (Ks) is a common and essential parameter for most of soil physical investigations due to the connected relation of (Ks) to many of soil water relations as water conservation, irrigation scheduling, drainage planning and soil-plant relationships . Since many methods for determining (Ks) can be conducted in the field as well as in the laboratory, the obtained data could be varied for the same soil. Usually, measurements of hydraulic conductivity in the lab. or in the field is tedious, expensive and require excessively large numbers of readings. Many scientists and researchers carried out many investigations about soil water conductivity as affected by different physical and chemical properties of the soil (Camplell and Camplell, 1982; Saffan, 1984; Saxton et al.,1986; Gallichand et al., 1990; El-Samanoudi, 1992; Yosry, 1992;Abdel-Nasser, 1995; Chen et al., 1998; Arya et al., 1999 and El-Henawy, 2000) .

Researchers may have developed or used one method for measuring water hydraulic conductivity on definite soil samples . Therefore, the obtained data for (Ks) may be exchanged as another method for the same sample was used . Therefore, the main objectives of this study were to :

1- Measure saturated hydraulic conductivity for normal soils(non-saline non-sodic) with three different methods (constant head, falling head and auger-hole methods).
2- Calculate the relationship and correlation between the different obtained values for a definite soil sample and its physical and chemical properties.
3- Establish correlation coefficient that describe the relationships between (Ks) values which obtained by constant head, falling head and auger-hole methods .

MATERIAL AND METHODS

Four soil profiles from Kafr El-Sheikh governorate (Byalla district) were chosen in different locations representing normal soils (non-saline non-sodic soils according to Richareds,1954 and James et al.,1982).

Disturbed and undisturbed soil samples were taken from the successive soil depths of 0-30; 30-60 and 60-90 cm, respectively. Undisturbed soil samples were taken using core samples to determine bulk density, hydraulic conductivity and aggregate size distribution. Disturbed soil samples were air dried, gently ground with wood paste, sieved through 2 mm sieves and kept in plastic bags for soil analysis. Physical and chemical properties were determined using the following methods :

Particle size distribution was carried out according to Gee and Bauder (1986). Aggregate size distribution was determined by wet sieving technique(Yoder,1936) using sieves with 2.00,1.00,0.50,0.25 mm screen opening according to klute (1986). Total of water stable aggregation (Total of W.S.A) was calculated according to Ibrahim, (1964); aggregation index (AI), and mean weight diameter (MWD) according to Baver et al., (1972). Optimum size of aggregates (Opt.size) was measured after Kohnke,(1968) and structure coefficient (SC) according to El-shafei and Ragab, (1975) Bulk density(B_d) was determined using the method described by Vomocil,(1957). The saturated hydraulic conductivity was determined by three methods: constant head method (Klute, 1986), auger hole method to a depth of90 cm (Van Beers,1958) and falling head method (Klute, 1986). EC_e of the soil saturation extract, soluble cations and anions, pH, organic matter, cation exchange capacity, exchangeable cations and total calcium carbonate were determined according to the conventional methods described by (Jackson, 1958 and piper, 1950).

Correlation coefficients and multiple regression between saturated hydraulic conductivity and each of the studied properties were done after Snedecor and Cochran,(1967).

Results and Discussion

1- General soil characteristics :

The values of some physical and chemical properties are shown in Tables 1 and 2 respectively Data revealed that, the bulk density (B_d) ranged between 1.12 to 1.27 and 1.29 to 1.36gm/cm^3 reveal in (0-30) and (30-60) cm respectively. Generally B_d values increased with depth in all soil profiles. Total carbonate content of all the soil samples in different profiles , indicated no calcification as it ranged between 0.9 to 2.30% and, decreased with increasing soil depth in all profiles studied. Data in Table 1 showed that , soil texture in all of the profiles is clayey , whereas the clay, silt and sand content ranged between 51.4 to 52.2%, 25.3 to 25.9% and 20.3 to 24.9% in 0-30 cm respectively .

Data in Table (1) showed that total of water stable aggregates > 0.25 mm was ranged between 70.04 to 75.72%,(in 0-30 cm). In addition its values decreased with increasing soil depth. Values of aggregation index (A.I), mean weight diameter (MWD) and structure coefficient (SC) in (0-30 cm) ranged between 0.561 to 0.840, 1.121 to 1.668 mm and 2.34 to 3.12. respectively .

Table 1. Saturated hydraulic conductivity (Ks) as measured by different methods and some physical properties of the studied soil profiles .

Soil Properties		Profiles											
		P_1			P_2			P_3			P_4		
		Depth , Cm											
		0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
Ks	Constant-head method cm h^{-1}	0.24	0.24	0.18	0.24	0.18	0.12	0.24	0.24	0.12	0.30	0.24	0.18
	Falling-head method cm h^{-1}	0.18	0.15	0.12	0.21	0.16	0.12	0.19	0.16	0.12	0.22	0.15	0.13
	Auger-hole method cm h^{-1}	0.07			0.10			0.08			0.10		
Bulk density gm/cm^3		1.27	1.32	1.39	1.12	1.29	1.31	1.20	1.36	1.35	1.17	1.29	1.32
$CaCo_3$ %		2.20	1.20	0.80	1.80	1.60	1.00	2.00	1.40	0.90	2.30	1.10	0.60
Practical size* distribution	Sand%	22.70	23.40	22.90	22.50	22.60	22.40	22.60	23.00	22.40	22.60	23.40	22.60
	Silt %	25.90	27.30	26.10	25.30	24.70	25.50	25.60	26.00	25.00	25.70	27.10	25.90
	Clay	51.40	49.30	51.00	52.20	52.70	54.10	51.80	51.00	52.60	51.70	49.50	51.50
Total of W.S.A %		70.04	68.08	56.31	75.72	71.82	50.83	72.88	68.58	57.75	72.82	69.08	56.35
aggregation index (AI)		0.56	0.69	0.30	0.84	0.83	0.28	0.70	0.76	0.30	0.84	0.69	0.30
MWD m.m		1.121	1.381	0.597	1.668	1.654	0.560	1.396	1.513	0.592	1.680	1.374	0.596
Optimum size of aggregates (OP.size)		56.79	51.34	55.77	50.38	49.47	47.88	53.59	50.41	51.83	49.47	51.34	55.77
structure coefficient(SC)		2.34	2.13	1.29	3.12	2.55	1.03	2.73	2.18	1.37	2.52	2.10	1.27

* The soil texture is clayey in all the studied samples.

Table 2. Some chemical properties of the studied soils profiles .

Soil Properties		Profiles											
		P_1			P_2			P_3			P_4		
		Depth , Cm											
		0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
PH (1:2.5) soil : water		8.28	8.17	8.27	8.12	8.22	8.19	8.17	8.20	8.19	8.18	8.21	8.13
EC_e dS/m		2.31	3.27	3.99	2.84	2.48	3.33	2.58	2.88	3.68	2.35	3.25	3.98
Soluble cations meq/L	Na^+	2.33	1.03	4.73	7.00	7.18	9.42	0.43	3.52	3.93	2.82	3.30	2.12
	Ca^{++}	13.00	17.60	7.40	13.90	10.05	10.30	13.90	13.90	9.30	14.80	15.50	5.60
	Mg^{++}	7.40	13.90	27.80	5.60	7.30	13.20	11.10	11.10	23.20	5.60	11.90	32.00
	K^+	0.37	0.37	0.37	1.90	0.27	0.38	0.37	0.28	0.37	0.28	1.80	0.38
Soluble anions meq/L	$Co^{=}_3$	1.90	-	0.93	1.90	1.80	1.90	1.90	0.93	0.93	1.90	1.80	0.94
	HCO^-_3	16.7	9.38	12.1	7.40	5.50	9.40	14.90	10.20	12.10	9.30	7.30	5.60
	Cl^-	0.46	15.00	15.60	13.00	10.10	13.00	4.60	10.30	15:70	10.20	12.30	17.80
	SO^-_4	4.04	8.40	11.70	6.10	7.40	9.00	4.40	7.40	8.10	2.10	11.10	15.66
O.M %		1.68	0.65	0.56	1.90	0.63	0.53	1.80	0.64	0.55	1.50	0.63	0.54
Exchangeable cations meq/100 gm soil	Na^+	2.30	3.30	3.50	1.50	2.20	2.60	2.40	2.80	3.30	2.60	2.70	3.40
	Ca^{++}	20.50	15.90	15.70	22.60	13.90	17.10	21.60	14.90	16.40	20.30	15.60	15.50
	Mg^{++}	13.00	11.10	9.90	15.80	9.90	8.90	14.40	10.50	9.40	16.00	11.00	9.70
	K^+	1.12	1.02	1.16	0.75	0.86	1.27	0.89	0.94	1.22	1.27	1.7	1.24
C.E.C.		37.22	31.42	30.66	41.35	27.66	30.77	39.29	29.54	30.72	41.37	31.40	30.64
Ex. Ca P		55.10	50.60	51.20	54.70	50.30	55.60	54.90	50.50	53.40	55.00	50.60	55.80
Ex. MgP		34.90	35.30	31.10	38.20	35.80	28.90	36.60	35.60	30.00	34.60	35.00	30.90
ESP		6.20	10.50	11.40	3.60	7.90	8.50	6.10	9.50	10.70	6.30	8.60	11.10
Soil diagnosis		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal

Data in Table (1) revealed that Ks values determined by constant head method were ranged between 0.24 to 0.30 cm/h in (0-30 cm), while the corresponding values of Ks determined by falling head method were ranged between 0.18 to 0.22 cm/h .On the other hand Ks values determined by auger hole method were ranged between 0.07 to 0.1 cm/h in the studied soil profiles .

Data in Table (2) showed that electrical conductivity (ECe) values, ranges between 2.31 and 2.84 dS/m, pH values fluctuate between 8.12 and 8.28, organic matter percent, ranges from 1.50 to 1.90%, and the soluble Na^+ values were lesser than the summation of soluble Ca^{++} and Mg^{++} in 0-30 cm). Also data in Table (2) revealed that in (0-30)cm exchangeable sodium percentage (ESP) was less than 15% and it's values range between (3.6 and 6.1%), Ex. Ca P values ranged between 54.7 and 55.1%, Ex. MgP ranged between 34.6 and 38.2% and C.E.C. fluctuates between 37.22 and 41.37 meq/100 g soil. Exchangeable Ca or Mg predominate on the exchangeable complex in the all studied profiles.

2- The relation between saturated hydraulic conductivity (Ks) by constant head methods and some soil variables :

Ks has highly positive significant correlation with aggregation index (AI) (R^2 = 0.6323**), mean weight diameter (MWD) (R^2 = 0.6439**) and total of water stable aggregates > 0.25 mm (WSA %) (R^2 = 0.8814**), while it had a positive significant correlation with structure coefficient (S.C) (R^2= 0.5524*) (Table. 3).

Multiple regression equation was calculated between the investigated Ks and the four independent variables of soil structure was:

Ks = -0.414-26.860 (AI) + 13.41 (MWD)-0.0553 (S.C) + 0.0116 (WSA%) (R^2 = 0.775, insignificant).

Table 3. The linear regression between Ks determined by constant head method and some physical and chemical properties .

Particular		Linear regression equations	R^2
Y	X		
Ks cm/h	WSA %	Y = -0.208 + 0.0063 x	0.6814**
	AI	Y = 0.0727 + 0.2211 x	0.6323**
	MWD (mm)	Y = 0.0711 + 0.42 x	0.6439**
	S.C	Y = 0.0623 + 0.0699 x	0.5524*
	Exchangeable Mg^{++} (meq/100 g soil)	Y = 0.0129 + 0.0169 X	0.5877**
	$CaCO_3$ %	Y = 0.092 + 0.08 X	0.4921*
	Soluble Ca^{++} (meq/L)	Y = -0.0192 + 0.0178 X	0.6509*
	Soluble Mg^{++} (meq/L)	Y = 0.2971 - 0.0074 X	0.4433*

** Highly significant at level 1%

* Significant at level 5%.

The obtained results are in agreement with those found by; Zein El-Abedine (1979), Talha et al. (1979), Abdel-Rasoul et al. (1999). They reported that aggregation parameters of soil are significantly and positively related with the Ks.

Ks had highly positive significant correlation with soluble calcium (R^2= 0.6509**) and a exchangeable magnesium (R^2 = 0.5877**) while it had a positive significant correlation with calcium carbonate % (R^2= 0.4921*). On the other hand, soluble magnesium had a negative significant correlation with Ks (R^2= 0.4433*), (Tables 3). Multipleregression equation between (Ks) and the independent variables of chemical properties, could be expressed as follows :

$$Ks = -0.110 + 0.014 (\text{soluble } Ca^{++})^{*} - 5.77 E\text{-}04 (\text{soluble } Mg^{++}) + 1.581 E\text{-}05 (\text{exchangeable } Mg^{++}) + 0.0518 (CaCO_3 \%). \quad (R^2 = 0.934^{*}).$$

It's obvious that, soluble Ca^{++} had the most important parameter which can effect the saturated water flow in the soil. The obtained results are confirmed with those found by Mustafa (1969) who pointed out that the effect of different chloride salts on the permeability coefficient could be arranged in the following order: $CaCl_2 > MgCl_2 > NaCl$. Oster et al. (1980) found that the suitable presence of divalent ions increase the soil hydraulic conductivity. The same conclusion was found by Madkour et al. (1999).

3- The relation between saturated hydraulic conductivity (Ks) by falling head method and some physical and chemical properties:

Ks had highly positive significant correlation with structure coefficient (R^2= 0.7409**), total water stable aggregate > 0.25 mm (R^2= 0.6843**) and positive significant correlation with aggregation index (R^2= 0.5726*), mean weight diameter (R^2= 0.5741*), and highly negative significant correlation with bulk density (R^2=0.7671**) (Table 4).

Also, multiple regression equation was calculated between the investigated Ks and the five independent variables of physical properties and can be expressed as follows:

$$Ks = 0.375 - 0.324 (B_d) - 7.358 (AI) + 3.676 (MWD) - 0.0305 (S.C) + 0.004 (WSA \%) \ (R^2 = 0.925^{*}).$$

The obtained results are confirmed with those found by (Abdel-Nasser, 1995) who found that clay and sand fractions and bulk density are a good estimation of Ks and concluded that mean weight diameter could be used for the predication of the Ks. Also Zein El-Abedine (1979) and Talha et al. (1979) found that the bulk density had a significant and negative effect on the hydraulic conductivity.

Table 4. The linear regression between (Ks) determined by falling head method and some physical and chemical properties .

Particular		Linear regression equations	R^2
Y	X		
Ks cm/h	WSA %	Y = -0.0755 + 0.0036 X	0.6834**
	B_d	Y = 0.6246 -0.3623 X	0.7671**
	MWD	Y = 0.0878 + 0.0596 X	0.5714*
	AI	Y = 0.0877 + 0.1198 X	0.5726*
	S.C.	Y = 0.0643 + 0.0457 X	0.7409**
	Exchangeable Mg^{++}	Y = 0.0219 + 0.0119 X	0.9114**
	Exchangeable Ca^{++}	Y = 0.0288 + 0.0076 X	0.5119*
	(meq/100 gm soil)		
	(C.E.C.) meq/100 gm soil	Y = -0.0152 + 0.0058X	0.7074**
	$CaCO_3$ %	Y = 0.075 + 0.0582 X	0.8106**
	ECe (dS/m)	Y = 0.3239 - 0.055 X	0.5935**
	Soluble Mg^{++} (meq/L)	Y = 0.2195 - 0.0049 X	0.6192**
	E.S.P	Y = 0.2608 - 0.0123X	0.6804**
	O.M %	Y = 0.1142 + 0.0489 X	0.7359**

** Highly significant at level 1%
* Significant at level 5%.

Ks had highly negative significant correlation with electrical conductivity (R^2= 0.5935**), soluble magnesium (R^2= 0.6192**), exchangeable sodium percentage (R^2= 0.6804**) and highly positive significant correlation with calcium carbonate (R^2= 0.6104**), exchangeable magnesium (R2= 0.9114**), cation exchangeable capacity (R^2= 0.7074**) and organic matter content (R^2 = 0.7359**) and positive correlation with exchangeable calcium (R^2= 0.5119*). (Tables 4).

From data obtained it was noticed that the (Ks) increased with increasing exchangeable Ca, exchangeable Mg, (C.E.C), ($CaCO_3$%) and organic matter content, while it decreased with increasing electrical conductivity (ECe), soluble Mg, and exchangeable sodium percentage. Therefore, it could be concluded that the previous chemical properties of normal soils are the properties, to which (Ks) is most directly related.

Also, multiple regression equation was calculated between (Ks) of the investigated soils and seven independent variables of chemical properties it expresses as:

Ks = 0.399 + 0.0322 (O.M %) - 0.029 ($CaCO_3$%) -0.031 (ECe)-8.321 E-05 (soluble Mg^{++}) + 0.0267 (exchangeable Mg) -0.007 (C.E.C.)-0.0019 (ESP) (R^2 = 0.999*).

Similar results are obtained by (Abdel-Rasoul et al. (1999). They found that the hydraulic conductivity has significant and negative related to ESP. Also, Madkour et al. (1999) showed that Ks has positive significant correlation with organic matter %.

4- The relationship between Ks by auger hole method and by constant and falling head methods:

Simple correlation were calculated to predict the relation between the different three methods for determining hydraulic conductivity, i.e. auger hole method, constant-and falling head method in normal soils. It showed no significant correlation between the auger-hole method and both constant and falling head methods .

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الملخص العربى

تأثير الخواص الطبيعية والكيميائية للأرض العادية على التوصيل الهيدروليكي المقدر بطرق مختلفة

تم أخذ أربعة قطاعات من الأراضي العادية (غير الملحية وغير الصودية) من مركز بيلا محافظة كفرالشيخ ، وقد تم تقدير بعض الخواص الطبيعية والكيميائية فى هده القطاعات . وقد تم عمل التحليل الإحصائي بطريقة الانحدار الخطي البسيط والمتعدد لجميع القيم المقدرة للتوصيل الهيدروليكي في الحالة المشبعة بالطرق الثلاثة (الضاغط الرأسي الثابت ، الضاغط الرأسي المتغير ، طريقة حفرة الأوجر) ، وجميع الخواص الطبيعية والكيميائية المقدرة في تلك القطاعات.

ويمكن تلخيص أهم النتائج فيما يأتى:

١- التوصيل الهيدروليكي في الحالة المشبعة والمقدر بطريقة الضاغط الرأسي الثابت تأثر بحالة التحبب للتربة حيث وجد ارتباط موجب عالي المعنوية مع كل من المجمعات الثابتة فى الماء ذات القطر أكبر من ٠,٢٥مم (R^2 =0.6814**) ودليل التحبب (R^2 = 0.6383**) و نصف القطر الموزون (R^2 = 0.6439**). هذا وقد كانت العلاقة معنوية موجبة بين معامل البناء والتوصيل الهيدروليكي (R^2=0.5524*).وعلى العكس من ذلك فإن الانحدار المتعدد بين التوصيل الهيدروليكي المشبع والأربعة خواص المستقلة للبناء قد أوضحت عدم وجود ارتباط معنوي. كذلك فقد وجد أن هناك ارتباط موجب عالي المعنوية بين التوصيل الهيدروليكي المشبع وكل من الكالسيوم الذائب (R^2=0.6309**) والماغنسيوم المتبادل (R^2=0.5577**). وقد وجد أيضا ارتباط معنوي موجب مع كربونات الكالسيوم الكلية (R^2=0.4921*). وعلى الجانب الآخر وجد أن هناك ارتباط معنوي سالب بين الماغنسيوم الذائب والتوصيل الهيدروليكي(R^2=0.4433*). وقد أوضح الانحدار الخطى المتعدد بين الخواص الكيميائية المذكورة سابقا والتوصيل الهيدروليكي للأرض أن بينهما ارتباط معنوي (R^2=0.934*). وكان واضحا من النتائج أن الكالسيوم الذائب هو أهم الخواص الكيميائية المؤثرة في التوصيل الهيدروليكي المشبع.

٢- للتوصيل الهيدروليكي المشبع والمقدر بطريقة الضاغط الرأسي المتغير فقد تأثر بشدة بحالة التحبب في الأرض حيث وجد التوصيل المائي يرتبط ارتباط موجب عالي المعنوية مع كل من المجمعات الثابتة في الماء والتي أقطارها اقل من ٠,٢٥مم (R^2=0.6824**) وكذا معامل البناء (R^2=0.7409**).وقد لوحظ أن هناك ارتباط معنوي موجب مع كل من نصف القطر الموزون (R^2 = 0.5714*) ودليل البناء (R^2 = 0.5726*).

وبالنسبة للكثافة الظاهرية فقد أظهرت النتائج أنها تؤثر بدرجة كبيرة على التوصيل الهيدروليكي المشبع حيث هناك ارتباط سالب عالي المعنوية بين التوصيل المائي والكثافة الظاهرية للأرض (R^2=0.7671**).وقد أوضحت معادلة الانحدار الخطي المتعدد بين الخواص الطبيعية المذكورة سابقا والتوصيل الهيدروليكي أن هناك ارتباط معنوي (R^2=0.925*) بينهما. وكان من الواضح أن الكثافة الظاهرية هي أهم العوامل التي تؤثر في التوصيل الهيدروليكي. وقد كان واضحا أن الخواص الكيميائية للأرض قد أثرت بدرجة أو بأخرى على التوصيل الهيدروليكي المقدر بطريقة الضاغط الرأسي المتغير حيث كان هناك ارتباط موجب عالي المعنوية بين التوصيل الهيدروليكي وكل من الماغنسيوم المتبادل (R^2=0.9114**) والسعة التبادلية الكاتيونية (R^2=0.7074**) ، كربونات الكالسيوم الكلية(R^2 = 0.8106**) ومحتوى المادة العضوية للأرض (R^2=0.7354**).وكذلك وجد أن الكالسيوم المتبادل كان له تأثير موجب على التوصيل المائي للتربة (R^2 = 0.5119**).بينما كان لزيادة كل من الماغنسيوم الذائب والنسبة المئوية للماغنسيوم المتبادل تأثير معنوي سالب على التوصيل الهيدروليكي للأرض (R^2 = 0.6192**, 0.6804** على الترتيب). وقد أوضح الانحدار الخطي المتعدد بين التوصيل الهيدروليكي المشبع والخواص الكيميائية المشار اليها عاليه وكان معامل الارتباط معنوي (R^2 = 0.999*).

٣- كذلك دلت النتائج على عدم وجود ارتباط معنوي بين قيم التوصيل الهيدروليكي المتحصل عليها بطريقة الضاغط الرأسي الثابت والضاغط الرأسي المتغير أو بطريقة حفرة الأوجر.