THE RELATIONSHIP BETWEEN INFILTRATION PARAMETERS AND SOME PHYSICAL PROPERTIES OF CALCAREOUS SOILS.

Journal

J. Biol. Chem. Environ. Sci., 2009, Vol. 4(2): 651-664
www.acepsag.org

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ABSTRACT

The present work aims at studying the relationship between some relevant physical properties and the infiltration process in calcareous soil. Two sites representing West Nubaria were were chosen for such a study. Eleven soil profiles, 4 in Tieba and 7 in Bangar El-Sokkar regions were selected to represent the studied areas. These profiles were field examined and representative samples for each soil layer were collected and analysed. Infiltration tests were carried out very close to each of the chosen profiles. Each test continued for about four hours. The depths of water infiltration into the soil surface in the consumed time were processed to fit the Kostiakov equation (1932) and the infiltration parameters were calcuated. Such parameters, i.e. basic rate and the "n" constant were staistically correlated with the sand, silt, clay, CaCO3, bulk density, porosity, soil peneration resistance and soil aggregates. The obtained regression equations were discussed. Briefly the obtained results indicated that both basic infiltration rate and constant (n) displayed significant positive linear functions with sand content, total porosity and mean wieght diameter of soil aggragates. On the other hand the two parameter displayed significant negative relationships with the percentage of clay, silt, CaCO3 and penetration resistance, (MPa).

INTRODUCTION

It is well known that infiltration is the process of water entry into the soil and its rate determines how much water from rainfal1 or land irrigation will enter the root-zone and how much, if any, will run off. Therefore knowledge of such process is a prerequisite for efficeint soil and water management. In this respect, a considerable amount of research has been carried out for describing and modeling infiltration process. Two types of models have been derived. These are either physically based models, e.g. Green- Ampt (1911) and Philip (1957) or empirical e.g. Kostiakov (1932) and Horton (1940). Due to the simplifing assumptions in their deriving and thus their limited ability for describing infiltration under field conditions, the physically based models are of limited use (Hillel, 2002), However, the most often used is the empirically drived ones especially Kostiakov equation, which is a simple power function and can be written as:

$$D = K t^n$$

Where;

(D) is the cumulative volume of water infiltrated in time,

(t) per unit area of soil surface and

(k) and (n) are constants.

Taylor (1964) illustrated that the parameter (K) indicates how fast water enters the soil initially and n indicates how the initial rate diminishes with time. Consequently, (n) is associated with the structural stability of the soil. He further suggested that, in a natural homogenous soil the value of “n” approaches 0.5 for the horizontal movement. Nevertheless, for the vertical movement (n) varies greatly. The same author proposed, generally that if “n” exceeds 0.7, the soil should be classified unsuitable for surface irrigation, and “n” if n is between 0.4 and 0.6, the soil would be satisfactory for surface irrigation, from the stand point of water movement. If (n) is less than 0.4 the soil would be classified as suitable for gravity irrigation.

Clemmens (1983) showed that infiltration is greatly affected by soil properties, surface condtions as well as the changes in soil parameters e.g. bulk density and permeability. Due to the fact that the calcareous soils are generally characterized by their relativelly coarse to medium texture, low organic matter and thus of weak structure, it is believed that factors other than structural stability will affect the infiltration parameters. Therefore the objective of the current study was to study the relationship between infiltration parameters and some of physical properties of calcareous soils in Egypt.

MATERIALS AND METHODS

The present work was carried out on the newly reclaimed calcareous soils of Nubaria area. Two sites, namely Tieba and Bangar El-Sokkar representing the northern and southern sites of El-Nasr Canal, were chosen for this study. Eleven soil profiles, 4 in Tieba and 7 in Bangae El-Sokkar were chosen to represent the most prevailing soil textural classes, CaCO3 content and management practices in the area. Each profile was morphologically studied. Disturbed and undisturbed soil samples were collected from the different layers, for laboratory analysis. Infiltration rate was determined using double ring infiltroeter, very close to each of the chosen profile. Such test was conducted under constant head of water, as recommonded by Klute (1986). The diameters of the inner and outer rings used were 23 and 45 cm, respectively. The length of the two rings approaches 35cm of which 15cm is reinforced into the soil. Each infiltration test lasted for about 4 hours.

The obtained data of infiltration expressed in water depth (cm) in time (t) in minutes was adequately described by the above mentioned Kostiakov formula. The relationship between both infiltration rate (i) and the prominant physical properties of calcareous soil were evaluated. Determinations of particle size distribution, soil bulk density, CaCO3 content, mean wieght diameter of stable aggregate and penetration resistance were carried out using the standard methods described by Ricahrd (1954) and Klute (1986). Meanwhile statistical analysis were carried out according to Spiegil (1961).

RESULTS AND DISCUSSION

Properties of the studied soils:

Results of the basic soil properties of the profiles representing Tieba and Bangar El-Sokkar sites, given in Table (1) can be discussed under the following:

A) Tieba Site:

Table (1) shows that the locations represented by profiles No. 1 and 2 are uniform in texture i.e. loamy sand throughout the profile depth. Meanwhile, the location represented by profile No. 3 is characterized by sandy clay loam texture in the upper 70cm which overlies clay loam in the bottom two layers. Also, the texture of the location represented by profile No. 4 is sandy loam in the top 120cm, overlying a bottom sandy clay loam layer. The same table also reveals that the values of bulk density of the suface two layers of the studied profiles range between 1.32 and 1.62 Mg/m^3. Concerning the $CaCO_3$ content, the data indicate that it varies from 4.39% to 19%, indicating that such soils are of calcareous nature. As for total porosity, the data given in Table (2) point out that it ranges, on average, from 36.93% in profile No. 3 to 41.75% in profile No. 4. Meanwhile, soil compactness expressed by the values of penetration resistance varied pronounce by from 1.7 MPa to more than 3.5 MPa. It is also evident that the mean weight diameter (MWD) of the stable aggregates ranges between 0.45 and 2.20 mm.

B) Bangar El-Sokkar:

Data in Table (1) indicate that profile No. 5, except the upper most soil layer, and the profile No. 6 are characterized by their clayey texture throughout the studied soil depth. Profile No. 11 is homogenous sandy loam texture. Meanwhile profile No. 7 is characterized by clayey texture in the top and bottom layers and clay loam in the middle layer. With respect to profile No. 8, the data point out the texture of the top two layers is loam overlying two clay loam layers. However, the texture of the profile No. 9. exhibits opposite trend where it characterized by its clay loam texture in the top layers overlying by sandy clay loam layers. The data also indicate that profile No. 10 is characterized by its sandy loam texture in the top layers and sandy clay loam texture in the bottom layers. As regard to carbonate content, the data given in Table (2) point out that such content is very high, as it ranges, on average, between 28.77% top layers (profile No. 10) and 52.50% (in the bottom layer of profile No. 9). This indicate that such site is highly calcareous compared to Tieba site. Considering the values table (2) bulk density, the obtained data elucidate that, the weighed values for the surface soil layer (50cm depth) ranges between 1.26 1 and 1.56 Mg/m^3.

Obviously, such values are generally lower than the corresponding values for Tieba site. Total porosity displayed and apposite trend.

Table (1) Basic soil physical properties of the studied sites

Site	Profile No.	Depth cm	Particle Size Distribution			Textural Class	B. D * Mg/m^3	P ** %	*** (PR) MPa	**** MWD mm	CaCO3 %
			Sand %	Silt %	Clay %						
Tieba	1	0-20	82.35	6.10	11.55	Loamy Sand	1.57	38.72	2.56	0.56	10.60
		20-80	82.13	5.28	12.59	Loamy Sand	1.62	38.58	2.59	0.50	15.07
		80-90	83.10	5.42	11.48	Loamy Sand	--	--	--	--	13.25
	2	0-25	84.88	4.80	10.32	Loamy Sand	1.54	40.68	1.65	0.51	4.31
		25-60	84.41	2.92	12.67	Loamy Sand	1.56	42.62	1.95	0.48	7.12
		60-100	83.88	5.32	10.80	Loamy Sand	--	--	--	--	8.28
		100-150	85.17	4.41	10.42	Loamy Sand	--	--	--	--	6.63
	3	0-25	48.27	24.73	27.00	Sandy clay loam	1.32	47.68	2.35	2.99	18.82
		25-55	47.81	23.66	28.53	Sandy clay loam	1.45	42.62	2.79	0.55	19.0
		55-70	48.85	22.21	28.94	Sandy clay loam	--	--	--	--	6.19
		70-110	45.45	24.47	30.08	Clay loam	--	--	--	--	8.25
		110-150	41.21	28.40	30.39	Clay loam	--	--	--	--	11.56
	4	0-35	71.63	13.78	14.59	Sandy loam	1.50	40.88	1.58	2.69	5.94
		35-55	74.51	10.10	15.39	Sandy loam	1.52	42.60	1.63	1.33	8.01
		55-120	76.95	2.68	20.37	Sandy loam	--	--	--	--	13.11
		120-150	69.68	4.61	25.71	Sandy clay loam	--	--	--	--	16.35
Bangar El Sokkar	5	0-25	49.41	16.59	34.05	Sandy clay loam	1.39	45.31	2.29	1.68	32.04
		25-50	31.59	23.29	45.12	Clay	1.33	47.63	2.89	2.63	31.06
		50-80	29.97	28.29	41.74	Clay	--	--	--	--	44.57
		80-100	35.07	16.62	48.31	Clay	--	--	--	--	40.16

Table (1) Continued.

Site	Profile No.	Depth cm	Particle Size Distribution Sand %	Silt %	Clay %	Textural Class	B. D Mg/m^3	P %	(PR) MPa	MWD mm	CaCO3 %
	6	0-15	38.31	17.11	44.58	Clay	1.49	41.57	2.83	3.38	36.48
		15-50	35.13	7.56	57.31	Clay	1.50	41.92	3.58	0.79	35.31
		50-100	31.40	27.34	41.26	Clay	--	--	--	--	52.97
		100-150	39.01	10.34	50.65	Clay	--	--	--	--	53.62
	7	0-15	32.92	22.51	44.57	Clay	1.38	45.67	2.91	2.59	47.57
		15-35	32.04	22.20	45.76	Clay	1.39	42.14	2.69	1.80	49.53
		35-75	33.56	31.88	34.56	Clay loam	--	--	--	--	31.72
		75-110	31.48	31.49	37.03	Clay loam	--	--	--	--	30.73
		110-15	20.16	37.23	42.61	Clay	--	--	--	--	32.69
	8	0-20	49.98	28.34	21.68	Loam	1.35	45.12	2.49	2.23	35.31
		20-55	41.36	33.82	24.82	Loam	1.38	45.67	3.39	1.21	41.85
		55-95	38.88	29.87	31.75	Clay loam	--	--	--	--	49.70
		95-150	40.27	29.51	30.22	Clay loam	--	--	--	--	46.59
	9	0-30	43.65	25.35	31.10	Clay loam	1.51	38.68	2.95	1.89	41.36
		30-50	41.13	25.20	33.67	Clay loam	1.60	39.98	3.92	1.50	52.48
		50-80	47.78	23.92	38.30	Sandy clay loam	--	--	--	--	33.68
		80-100	57.73	21.88	20.39	Sandy clay loam	--	--	--	--	32.86
		100-150	54.64	23.27	22.09	Sandy clay loam	--	--	--	--	31.06
	10	0-20	66.40	14.31	19.29	Sandy loam	1.23	49.36	2.05	1.93	28.77
		20-55	74.26	8.64	17.10	Sandy loam	1.29	47.83	3.34	1.34	30.73
		55-75	53.25	18.63	28.12	Sandy clay loam	--	--	--	--	31.22
		75-100	55.78	17.25	26.97	Sandy clay loam	--	--	--	--	24.20
	11	0-10	46.91	25.08	28.01	Sandy clay loam	1.31	44.73	2.48	1.50	32.53
		10-30	46.14	26.15	27.71	Sandy clay loam	1.38	46.92	3.63	0.98	42.43
		30-50	48.97	24.93	26.10	Sandy clay loam	--	--	--	--	35.15

Values of (B.D, P, PR and MWD) were determined only for the surface to successive leyers.
B. D* = Bulk Density
P** = Total Porosity
PR*** = Penetration resistance.
MWD**** = Mean weighted diameter.

As to the soil compactness, the data given in the same table, reveal that the penetration resistance varies from 2.2 MPa to 3.44 MPa indicating that such site is characterized by its high soil strength according to (Taylor 1971).

Infiltration parameters:

As mentioned before, infiltration test was carried out very close to each of the chosen profiles. In each test, the volume of water infiltrated under constant head of water, into unit area of soil surface (i) cm in time t (mintues) was processed to fit the Kostiakov equation (1932). It is worth to mention that at the expiry of each test the overlying water above the two rings, i. e. the inner and outer rings was removed and the soil was dug out along the diameter of the outer ring. The vertical distance of wetted zone was measured along the vertical axe. Due to the fact that in all cases the depth of wetted front ranges between 25 and 45cm, the values of soil properties were weighed up to 50cm of soil depth, Table (2), and the obtained weighed values were statistically correlated with the infiltration parameters i.e. basic rate and n parameter. Such calculations involved the linear exponential, logarithmic and power functions and the highest significant correlaction coefficient of determination was taken as indication for the most suitable function. The attained results can be given as follows:

A) Basic infiltration rate:

Table (3) and Figures (1 and 2) point out that the basic infiltration rates of the studied sites, i.e. Tieba and Bangar El-Sokkar vary from 0.054 to 4.84 cm/h indicating that the ability of such soils to transmit water varies from very slow to moderate according to the classification of permeability classes of O'Neal (1952) Obviously this behavior seems to be related to the size – distribution of soil particles, CaCO3 and their arrangement in structural forms which influence soil bulk density, porosity and meanwiegh diameter of soil aggregates.

Table (2): Weighted mean values of soil properties in Tieba and Bangar El- Sokkar sites.

Site	Profile No.	T. Sand %	Silt %	Clay %	$CaCO_3$ %	PR (MPa)	P %	B. D Mg/m^3	MWD mm
Tieba	1	82.24	5.69	12.07	12.84	2.43	38.65	1.60	0.45
	2	84.65	3.86	11.50	5.72	1.80	41.65	1.55	1.66
	3	48.04	24.20	27.77	18.91	3.57	36.93	1.65	0.49
	4	73.07	11.94	14.99	6.98	1.71	41.75	1.51	2.20
Bangar El- Sokkar	5	40.50	19.92	39.59	31.55	2.59	46.47	1.32	2.16
	6	36.72	12.34	50.95	35.90	3.21	41.75	1.50	1.57
	7	32.48	22.36	45.17	48.55	3.30	43.91	1.39	1.25
	8	45.67	31.08	23.25	38.58	2.94	45.40	1.37	1.27
	9	42.39	25.23	32.39	46.92	3.44	39.30	1.56	1.33
	10	70.33	11.48	18.20	29.75	2.20	48.60	1.26	2.25
	11	46.53	25.62	27.86	37.48	3.06	45.83	1.35	0.77

See footnotes of Table (1).

Table (3): Basic infiltration rates (cm/h) and values of "n" parameter for the investigated soil profiles.

Site	Profile No.	Infiltration parameters			Cumulative water after 240 min. (cm)
		Basic rate (i) cm/h	constant (n)	Class	
Tieba	1	1.997	0.245	MS	26.09
	2	3.590	0.532	M	28.27
	3	0.126	0.029	S	13.23
	4	4.081	0.493	M	28.53
Bangar El- Sokkar	5	3.443	0.391	M	35.31
	6	0.129	0.088	S	4.5
	7	1.211	0.124	MS	30.16
	8	3.135	0.627	M	17.92
	9	0.54	0.124	VS	1.34
	10	4.841	0.696	M	25.45
	11	0.469	0.196	S	7.55

In order to express mathematically the relationship between the basic infiltration rate in the two sites and each of these properties, correlation and regression statistical analysis were carried out and the obtained formulae are given in Table (4). The obtained formulae generally, indicate that sand content, exhibits highly significant linear relationship with basic infiltration rate. This behavior could be ascribed to its effect on increasing the macropores. On the other hand, basic infiltration rate displayed significant negative linear function with each of silt and clay content. The obtained equation indicates that as each of silt and clay increases by 10% soil basic infiltration rate of the soil progressively decreases with 17.7 and 22%, respectively. In the same direction the basic infiltration rate exhibited a significant negative linear relationship with $CaCO_3$ content. The derived regression equation reveals that as $CaCO_3$ content increases by 10% the steady - state infiltration rate progressively decreases by 13.8%. This behavior could be explained on basis of the fact that CaCO3 in the relatively fine textured calcareous soil generally dominates in the finer fraction, i. e. silt and clay, consequently it negatively affects the water movement within the soil profile (Afifi, 1974).

As regard to the soil compactness, the obtained results indicated that there are a highly significant negative linear function between basic infiltration rate and penetration resistance (PR). The derived formula indicates that increasing the penetration resistance to 2 MPa, the basic infiltration rate decreases by 54% and further increase in PR to 3MPa, the basic rate diminishes by 81%.

Concerning the soil porosity, which is the outstanding factor affecting water entry and movement through the soil, the obtained data show that it displays a significant positive linear relationship with the basic infiltration rate. The derived function proves that as soil porosity increases by 10%, the basic infiltration rate increases by 28%. Likewise, mean weight diameter of stable aggregates displays similar trend to that manifested for total porosity. As to the soil bulk density, the data indicated a significant negative linear relationship between its values ($Mg.m^{-3}$) and basic infiltration rate (cm/h).

The obtained formula reveals that every $0.1 Mg/m^3$ increment of bulk density leads to diminishing the basic infiltration rate by 0.6 cm/h. These findings are in line with those obtained by Fahmy (1991).

B) "n" parameter:

As mentioned before, the parameter "n" is the slope of infiltration curve resulted from the graphical representation of Kostiakov equation in its integrated form. According to Taylor (1964) such parameter equals 0.5 for the horizontal water movement in homogenous soils, but for vertical water movement it displays greater variations, and should be subjected to further detailed studies before being used for judging the suitability of irrigation system.

Table (4): The regression equations for the relationships between each of the basic infiltration rate (cm/h) as well as the constant "n' and each of the considered soil properties.

y	x	r	Regression
i	**Total sand**	**0.837****	**Y = 0.054 X – 0.802**
	Clay	**- 0.636***	**Y = 4.172 – 0.074 X**
	Silt	**- 0.609***	**Y = 3.502 – 0.077 X**
	$CaCO_3$	**- 0.678***	**Y = 3.546 – 0.049 X**
	PR	**- 0.848****	**Y = 8.391 – 2.272 X**
	Total porosity	**0.610***	**Y = 0.253 X – 8.687**
	Bulk density	**- 0.616***	**Y = 10.932 – 6.020 X**
	MWD	**0.719***	**Y = 7.321 X – 0.953**
n	**Total sand**	**0.714***	**Y = 0.054 X – 0.802**
	Clay	**- 0.629***	**Y = 4.172 – 0.074 X**
	$CaCO_3$	**- 0.699***	**Y = 3.546 – 0.049 X**
	PR	**-0.754****	**Y = 8.391 – 2.272 X**
	Total porosity	**0.607***	**Y = 0.253 X – 8.687**
	Bulk density	**-0.609***	**Y = 10.932 – 3.767 X**
	MWD	**0.656***	**Y = 0.766 X – 0.004**

In the current work, the obtained data of cumulative infiltration for about 4 hours was processed to fit Kostiakov equation (1932) and the values of parameter "n" were calculated. The obtained values were statistically correlated with the above mentioned soil properties, viz., soil mechanical separates, and the other properties including CaCO3, bulk density, mean weight diameter, porosity and penetration resistance. The obtained data revealed significant correlation between the values of "n" parameter and each of these properties. Therefore, regression analysis was calculated between each of these variables and the obtained function and presented in Table (4). These functions proves that the impact of the studied soil properties on n value is nearly similar to that attained for the basic infiltration rate. Thereby, one may conclude that "n" parameter depends basically on soil properties especially the size distribution of soil particles and the structural stability.

Moreover the obtained equations can be used for determining the values of n parameter as a function of these properties.

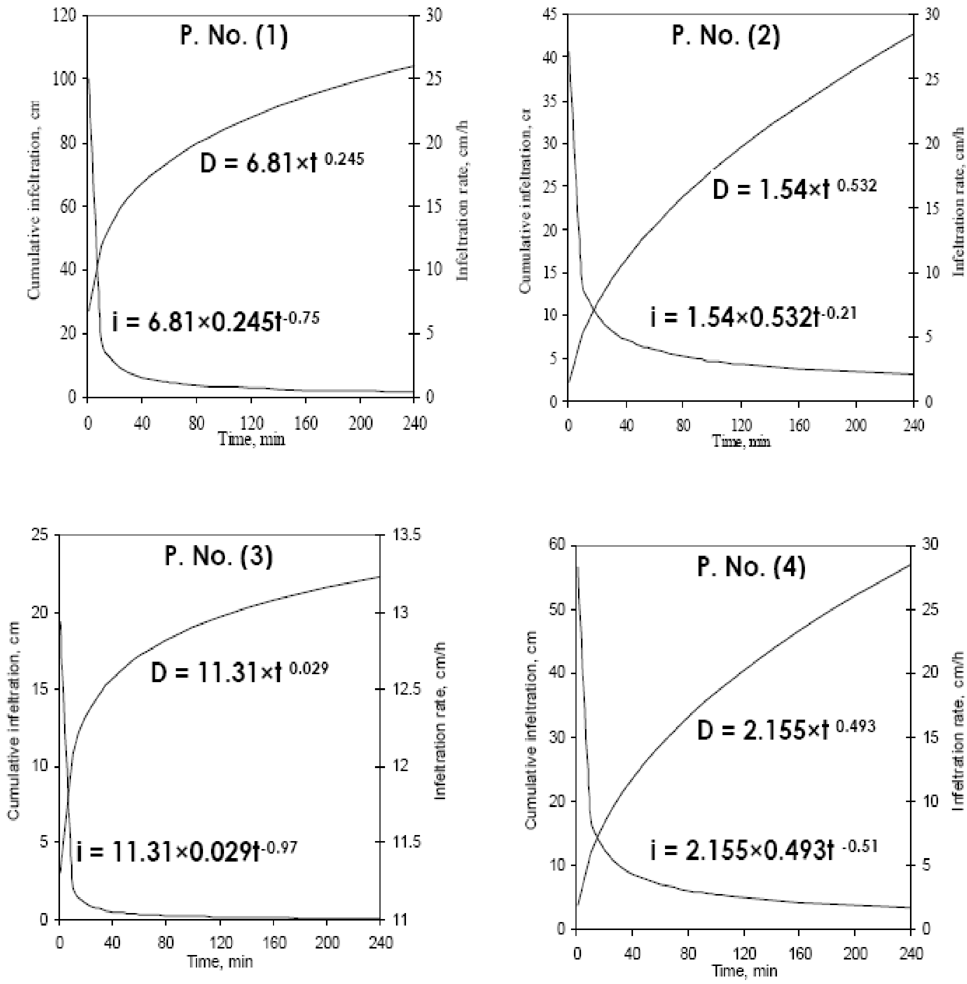

Fig. (1): Instantaneous and cumulative infiltration of Tieba soil profiles.

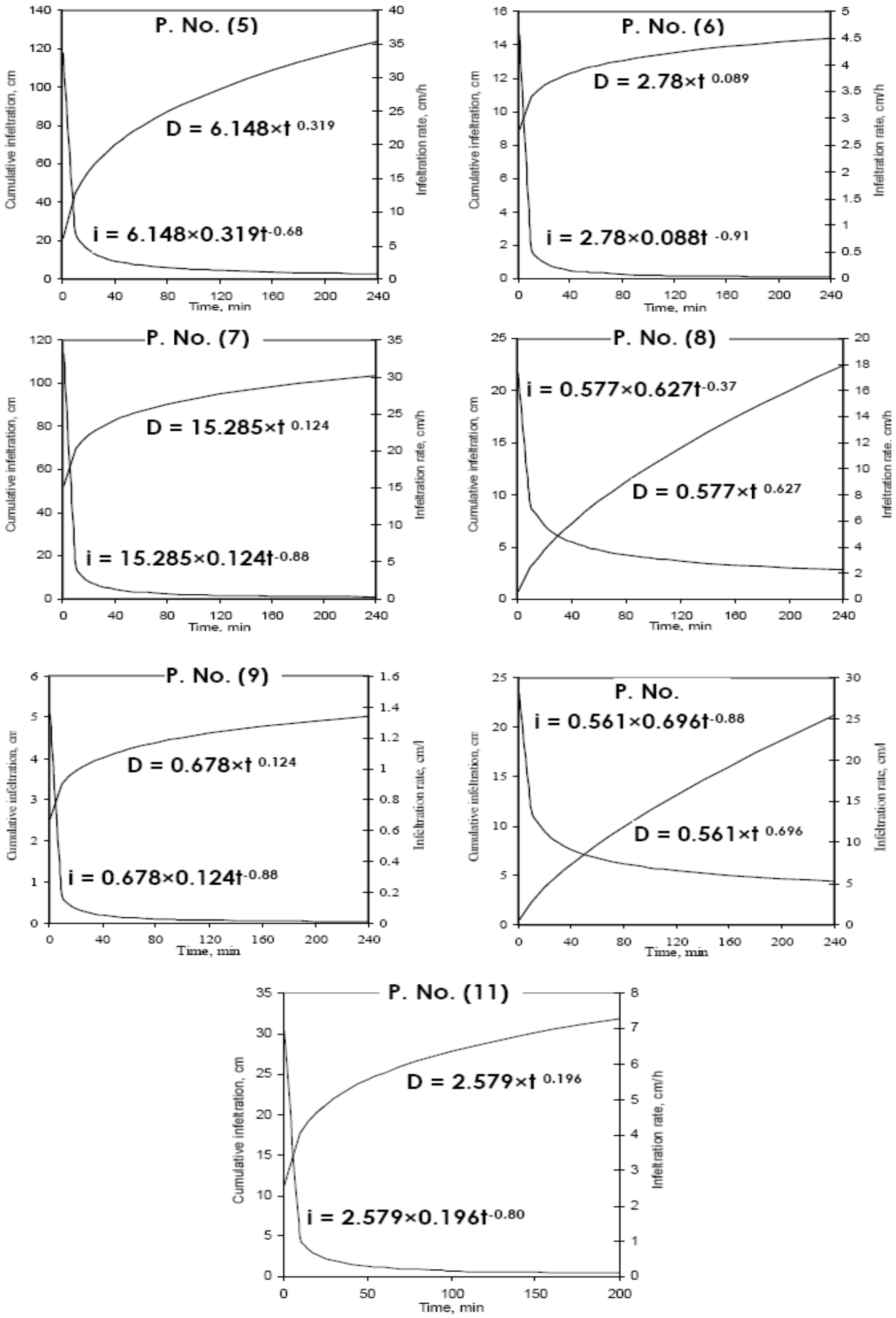

Fig. (2): Instantaneous and cumulative infiltration of Bangar El-Sokkar soil profiles.

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العلاقة بين خصائص الرشح وبعض الخواص الفيزيائية للأراضى الجيرية

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مركز بحوث الصحراء[1] - كلية الزراعة - جامعة بنها[2] .

يهدف هذا البحث إلى دراسة العلاقة بين معدل الرشح وبعض الخواص الفيزيائية للأراضى الجيرية ذات الصلة. وقد اختير لهذه الدراسة عدد 11 قطاعاً تمثل موقعين لأراضى منطقة غرب النوبارية هما موقع طيبة (4 قطاعات تربة) وموقع بنجر السكر (7 قطاعات تربة) – وقد تم دراسة هذه القطاعات فى الحقل وتم أخذ عينات ممثلة للطبقات المختلفة بكل قطاع، وتم تحليلها معملياً. كذلك فقد تم تقدير معدل الرشح فى الحقل بجوار كل قطاع من هذه القطاعات المشار إليها، حيث استمر كل اختبار لمدة 4 ساعات.وقد تم تقدير عمق الماء الراشح إلى داخل قطاع التربة والزمن اللازم لذلك، وقد تم معالجة النتائج الحقلية المتحصل عليها لتتوافق مع معادلة كوستياكوف (1932) ثم تم حساب معدل الرشح الأساسى، الثابت (n) . وأجريت دراسة إحصائية لبيان العلاقة بين كل من معدل الرشح الأساسى والثابت (n) وبعض الخواص الفيزيائية للأراضى تحت الدراسة – خاصة مفصولات القوام أى محتوى الرمل الكلى، الطين، السلت، وكذلك الخواص الفيزيائية الأخرى كالكثافة الظاهرية، نسبة كربونات الكالسيوم، المسامية، المقاومة للاحتراق، متوسط القطر الموزون لتجمعات التربة MWD.

ودلت النتائج على وجود علاقة معنوية خطية موجبة بين كل من معدل الرشح الأساسى، الثابت n وبين الرمل الكلى والمسامية متوسط القطر الموزون MWD، فى حين أظهرت كل من معدل الرشح الأساسى والثابت n علاقة معنوية خطية سالبة مع كل من النسبة المئوية للطين والسلت وكربونات الكالسيوم وكذلك مع قيم المقاومة للاختراق MPa.