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AN ACCURATE DETERMINATION OF FIELD CAPACITY BASED ON SOIL MATRIC POTENTIAL- AND PORE DIAMETERS

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ABSTRACT

The aim of this work is to introduce a precise definition of the field capacity that is based on the moisture content, soil water potential and soil pore diameter. The concept uses the definitive relationships between the soil moisture content, soil matric suction and soil pore size. This approach is important as it would enable us to determine a more exact value of the field capacity for a given soil, rather than an approximate value that is traditionally based on some suction values of 0.1 or 0.3 bar or other values.

The approach followed here depends on identifying the inflection point on the van Genuchten model of soil moisture-retention, and the relationship between soil matric suction and soil pore diameter. Soil samples representing each of three regions in northern Egypt namly Nubaria, Borg El- Arab, and Edko were collected. The regions are. These regions represent different types of the newly reclaimed soils. In each site, three profiles were dug and different layers of each profile were sampled. The soils of these three regions differ in many characteristics and have different textures.

The results showed field capacity values (volume basis) of 0.2275, 0.2380, and 0.3610 for the Nubaria, Borg El-Arab, and Edko soils; respectively. These values were found to be associated with soil matric suction values of 62, 186, and 308 mbar, and with soil pore diameters of 60, 16, and 14 μm, for the three soils , respectively. Different correlations between soil field capacity values and some soil physical properties, namely the total porosity, the bulk density and sand and clay contents, reflected high significance and showed high determination coefficients.

Keywords: Field capacity, Matric potential, Soil pores, Soil moisture retention curve, van Genuchten Model, Total porosity, Residual soil moisture content.

INTRODUCTION

Different approaches are followed to define the concept of field capacity and to determine its value. A conventional approach is based on subjecting the saturated soil to a pressure of 0.1 bar (Pidgeon, 1972 and Stakman, 1974) or 0.3 bar (Richards and Weaver, 1944) and determining the moisture content retained in the soil at equilibrium. However, other values of applied pressure are sometimes used as well. For example, Wolf and Drosdoff (1977) determined the field capacity as the moisture content retained in the soil at suctions of 0.05 or 0.06 bars. Kirkham and Kunze (1962) examined the relationship between time interval from irrigation and this soil moisture content and reported that soils reach their field capacity when the moisture content-time curve becomes flat. That is when $d\theta/dt \approx$ constant.

Webster and Backett (1972) reported that soil water potentials after 48 hr from wetting do not generally exceed –0.05 bar. Hansen *et al* (1980) suggested that the calculation of available water by using the values of field capacity at 0.1 bar was more appropriate from the viewpoint of plant water use.

El-Gendy *et al.* (1994) indicated that there are two borders to field capacity, a maximum limit, at which the soil starts retaining (holding) water due to the effect of matric potential (capillary and surface forces), and a minimum one, at the point where the soil matric potential is a single function of the effect of moisture held in the soil.

In this work, the definition of field capacity is based on- and related to- the soil pore size and its relationship with the soil moisture content. The pore spaces may be classified according to their sizes and functions (Van Beers, 1974) to:

(a) Macropores; with sizes larger than 0.01 cm, whose main function is aeration and free drainage by gravity flow;
(b) Mesopores; with sizes between 0.01 and 0.003 cm. These are the water conducting pores (rapid capillary flow); and
(c) Micropores; with sizes between 0.003 – 0.0003 cm. These pores retain water and allow slow capillary flow of water.

The soil moisture retention characteristic curve is a soil characteristic feature that depends on a group of soil properties, particularly soil matric suction (Capillary and surface forces), water content, pore size distribution, and bulk density, among others.

The soil moisture characteristic curve can be determined using soil moisture retention data{$\theta = f(h)$}, where θ is the soil moisture content, and h, is the soil matric suction (taking a positive sign). The retention curve is an important soil characteristic for calculating the physical and hydrophysical properties in an indirect way. The van Genuchten's model for SMRC (1980) is based on five parameters (namely, θ_r, φ, α = ($1/h_b$), n, and m). θ_r and φ are constants for a given soil layer. The model is given by the equation:

$$\theta = \theta_r + (\varphi - \theta r)[1/(1+ \alpha h)^n]^m \quad \text{...} (1)$$

Where:

θ is the volumetric soil moisture content at a given soil matric suction, h, in mbar,

θ_r is the volumetric residual soil moisture content,

φ is the total soil porosity (which is equal to the volumetric saturated moisture content),

α is the inverse of the bubbling pressure (air entry suction), mbar, and n and m are constants that depend on the fitting of the sigmoid curve.

Brakensiek (1977) used matric suctions up to 1000 cm to determine the bubbling pressure (h_b) and a pore size index (λ). The later parameter (λ) is related to the van Genuchten constants**,** n and m by the simple relation: λ = nm (Rawls and Brakensiek, 1985). El-Gendy and Hassan (2001) found that van Genuchten's model is the best one for representing the soil moisture retention curve of north Sinai soil. El- Gendy *et al.*(2000) could with the combination work between van Genuchten's model and neutron calibration curve of neutron moisture meter to detect the soil matric suction on along the soil moisture retention curve of Ras Sudr soil(south Sinai).

El- Gendy *et al*. (1998) determined the soil moisture values of matrixpores (θ_{h}), which represent the upper limits of field capacity of Ras Sudr soil using the soil depletion curve. El-Gendy *et al.* (2000) studied the impact of saline irrigation water (EC_U =13.8 Ds/m and sodium concentration 1959 ppm) on θ_h values of Ras Sudr soil. They indicated that θ_h values had been increased with 22% resulted from sodium dispersion.

The work presented in this article is directed at defining and determining an "actual" or "exact" value of the field capacity, in terms of the soil moisture content, as well as the associated soil water potential and effective soil pore size.

Theory

It is known that the inflection point separates between the convexity and concavity on any curve. Soil macro and micropores are the main reason for finding the inflection point on soil moisture retention curve (semi- logarithmic scale). In this study, the inflection point is considered the starting of micropore effects (maximum border of field capacity, El- Gendy, 1994)

van Genuchten (1980) showed that the inflection point on the soil moisture retention curve could be determined using the following equation:

$$\theta_{inflection} = [\theta_{sat} + \theta_r] / 2 \quad \text{...} \quad (2)$$

Mualem (1976) introduced the dimensionless water content parameter (*S*), which be defined as the effective soil moisture content. This parameter is obtained from the soil moisture retention curve as:

$$S = (\theta - \theta_r) / (\theta_{sat} - \theta_r) \quad \text{...} \quad (3)$$

Substituting for θ from eq. (2) into eq. (3) yields:

$$S = \{[(\varphi + \theta_r) / 2] - \theta_r\} / [\varphi - \theta_r]$$
$$S = (\varphi - \theta_r) / 2\ (\varphi - \theta_r)$$
Then $$S = 1/2 \quad \text{..} (4)$$

Considering the above function, as well as the van Genuchten definition of the *S* function:

$$S = [1+(\alpha h)^n]^{-m} \quad \text{...} \quad (5)$$

and substituting for *S* from eq. (4) into eq. (5), The following inflection function can be derived:

$$h_{inflection} = 1/\alpha\ [(1/2)^{-1/m} - 1]^{1/n} \quad \text{.................................,,,,,............} (6)$$

The size of filled soil pores is determined as a soil matric function using the capillary rise formula (Vomocil ,1965):

$$h = (2\gamma \cos\beta)/(\rho_w g r) \quad \text{.......................................(7)}$$

Where:

h, is the height of rise in capillary tube (soil matric potential), cm or mbar,

γ, is the surface tension of water with density (ρ_w), dynes/cm,

g, is the acceleration due to gravity, cm/ sec^2

β, is the angle between water and surface of soil matrix, and

r, is the soil pore radius, cm.

Taking water at temperature 20° C:

γ =72.75 dyne/cm,

ρ_w = 0.998 g/cm^3,

g = 981 cm/sec^2, and

β = 0

The equation can thus be simplified to the form:

$$h = 0.297/d$$

or $\approx 0.3/d$ ....(8)

where d is the diameter of the soil pores and is equal to 2*r.*

The soil pore diameter as a function of soil matric potential will then be:

$$d = 0.3/h$$

where the dimension of soil pore diameter is cm. Consequently, the soil pore diameter can be calculated, in microns, as a function of soil matric potential via the equation:

$$d\mu = 0.3 \times 10^4 / h_{mbar} \quad \text{.......................................(9)}$$

or $$d\mu = 3000 \times h_{mbar}^{-1} \quad \text{.......................................(10)}$$

From the van Genuchten equation (Equation 1),

$$h = 1/\alpha\, [(\theta - \theta_r)^{-1/m} (\varphi - \theta_r)^{1/m} - 1]^{1/n} \quad \text{..................................(11)}$$

Substituting for h from Equation 11 into Equation 10, the following formula for $d\mu$ is obtained:

$$d\mu = 3000\, \alpha\, \{[(\theta-\theta_r)/(\varphi-\theta_r)]^{-1/m} - 1\}^{-1/n} \quad \text{.......................................(12)}$$

Equation12 represents a θ - $d\mu$ function and could be re-arranged to give

$$\Theta = \theta_r + (\varphi - \theta_r)\, [(d\mu / 3000\, \alpha)^{-n} + 1]^{-m} \quad \text{.......................................(13)}$$

MATERIALS AND METHODS

Soil samples were collected from three areas in Northern Egypt. Three soil profiles were dug in each site. These areas are: The Nubaria, Borg El- Arab, and Edko. These areas were chosen because they all represent the newly reclaimed land in Northern Egypt and yet have different soil physical characteristics, particularly texture. A total of twelve soil samples were collected from 4 soil layers (0-20, 20-40, 40-60, and 60-90 cm) of the three soil profiles of Nubaria soil . Nine soil samples were taken from 3 layers (0-20, 20-40, and 40-70 cm) of the three soil profiles representing Borg El- Arab soil; and nine soil samples were taken from three layers (0-25, 25-50, and 50-90 cm)of the three soil profiles representing the Edko soil.

The volumetric saturation soil moisture content θ_s is the moisture percentage that is equal to the total porosity of the soil, φ and is therefore computed as:

$$\theta_s = \varphi = 1-(\rho_b / \rho_s)$$

Where:

ρ_b = The soil bulk density, g/ cm^3, and

ρ_s = The particle density which was taken as 2.65 g/cm^3.

Undisturbed soil core samples, 5 cm in diameter and 10 cm in hight were collected. The cores were sealed in plastic bags, boxed and transported carefully to the laboratory. These soil samples were saturated by capillarity and left for 48 hours. The soil cores were then transferred to a pressure plate apparatus and the water content was determined after equilibration at matric suctions of 100, 300, 1000, 3000, 5000, 8000, and 15000 mbar, according to the procedure of Black (1965).

The pore size index (λ), defined first by Brooks and Corey (1964) was calculated according to Breakensek (1977) in order to determine the fitting parameters of soil moisture retention curve (van Genuchten's model, 1980). These parameters (m, n, and α) were calculated according to Rawls and Breakensek (1985).

Residual soil moisture contents (θ_r) were determined at 15000 mbar. It was noticed that for Nubaria soils $\theta_{8000mbar} = \theta_{15000\ mbar}$, which is apparently a result of the much coarser texture of this soil, relative to the other two soils.

The main chemical, physical and hydrophysical properties of the three soils were determined according to Black (1965). Analysis results are presented in Tables 1 to 6.

Field capacity values were calculated using equation 2. Soil matric suction at field capacity was estimated using equation 6, while soil pore diameters were calculated using equation 9. Soil pore diameter as a function of soil moisture content and soil moisture contents as a function of soil pore diameter were calculated using equations 12 and 13; respectively.

Statistical Analysis

Various statistical analyses of the data were performed using computer software packages. Simple linear best-fit procedure was used for correlation analysis and the multiple regression procedure was used for multivariable best-fit analysis. Significance of correlation coefficients was evaluated according to Steel and Torrie (1980).

Table 1: Chemical properties of the Nubaria soil.

Soil profile No.	Layer depth cm	EC dS/m	PH (1:2.5)	CaCO3 %	Cations (meq/100g soil)				Anions(meq/100g soil)		
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	CL^-	SO_4^{--}
1	00-20	0.34	8.15	9.5	0.75	0.20	0.70	0.05	0.70	0.55	0.25
	20-40	0.26	8.10	10.0	0.65	0.25	0.37	0.03	0.60	0.5 0	0.20
	40-60	0.24	7.89	8.5	0.60	0.20	0.38	0.02	0.50	0.50	0.20
	60-90	0.26	7.90	6.0	0.60	0.25	0.48	0.02	0.60	0.45	0.30
2	00-20	0.33	8.00	9.0	0.70	0.25	0.59	0.06	0.70	0.70	0.20
	20-40	0.34	8.15	9.5	0.55	0.35	0.72	0.08	0.55	0.85	0.30
	40-60	0.25	7.86	8.5	0.55	0.35	0.37	0.03	0.55	0.45	0.30
	60-90	0.22	7.90	6.5	0.55	0.25	0.29	0.01	0.45	0.35	0.30
3	00-20	0.26	8.01	8.5	0.55	0.25	0.49	0.01	0.55	0.60	0.15
	20-40	0.26	8.05	9.0	0.50	0.30	0.49	0.01	0.50	0.60	0.20
	40-60	0.24	8.00	7.0	0.50	0.30	0.39	0.01	0.50	0.55	0.15
	60-90	0.26	8.00	6.5	0.60	0.20	0.48	0.02	0.50	0.50	0.30

Table 2. Physical and hydrophysical properties of the Nubaria soil.

Soil profile No.	Soil depth, cm	Particle size distribution			Texture class	B.D g/cm³	Vol. Sat. φ	θ_V at different tensions (mbar)*					
		Sand %	Silt %	Clay %				100	330	1000	3000	5000	8000
1	0-20	85	9	6	L. Sand	1.60	0.3962	0.2000	0.1390	0.1200	0.1010	0.0920	0.0750
	20-40	88	7	5	L .Sand	1.70	0.3585	0.1711	0.1210	0.1100	0.1000	0.0915	0.0717
	40-60	88	6	6	L. Sand	1.70	0.3585	0.1700	0.1300	0.1200	0.0980	0.0860	0.0700
	60-90	92	4	4	Sand	1.80	0.3208	0.1600	0.1199	0.1001	0.0905	0.0816	0.0710
2	0-20	85	10	5	L. Sand	1.65	0.3774	0.2090	0.1450	0.1222	0.0890	0.0799	0.0685
	20-40	82	13	5	L. Sand	1.60	0.3962	0.2250	0.1550	0.1000	0.0900	0.0799	0.0610
	40-60	88	7	5	L. Sand	1.60	0.3962	0.1600	0.1100	0.0920	0.0810	0.0715	0.0633
	60-90	93	3	4	Sand	1.55	0.4151	0.1500	0.1200	0.0811	0.0710	0.0650	0.0500
3	0-20	80	14	6	L. Sand	1.50	0.4340	0.2630	0.1777	0.1300	0.1056	0.0847	0.0664
	20-40	81	13	6	L. Sand	1.55	0.4151	0.2440	0.1588	0.1160	0.0925	0.0765	0.0600
	40-60	86	9	5	L. Sand	1.60	0.3962	0.2211	0.1655	0.1260	0.0972	0.0798	0.0605
	60-90	92	6	2	Sand	1.60	0.3962	0.1820	0.1650	0.1321	0.11.0	0.0831	0.0500

Organic matter < 1.2%. * Soil moisture content at 15000 mbar was found to be approximately the same as at 8000 mbar.

Table 3. Chemical properties of Borg El-Arab soil.

Soil profile No.	Soil layer depth, cm	PH (1:2.5)	EC (1:5) dS/m	Ca CO_3 %	Soluble salts (meq/100 g soil)							
					Cations				Anions			
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^-	CL^-	SO_4^{--}
1	0 –20	8.02	0.38	36.0	0.95	0.25	0.61	0.09	0	0.85	0.90	0.20
	20-40	8.15	0.42	38.5	1.05	0.50	0.65	0.05	0	1.05	0.95	0.25
	40-70	8.11	0.41	32.5	1.00	0.55	0.50	0.04	0	1.00	0.75	0.34
2	0 –20	7.98	0.32	37.5	0.60	0.45	0.55	0.07	0	0.85	0.65	0.17
	20-40	8.20	0.42	39.0	0.95	0.45	0.60	0.09	0	0.95	0.75	0.39
	40-70	8.20	0.40	33.5	0.95	0.50	0.50	0.06	0	1.00	0.55	0.46
3	0 –20	8.00	0.30	35.0	0.75	0.25	0.50	0.05	0	0.75	0.65	0.15
	20-40	8.15	0.30	37.1	0.80	0.25	0.45	0.05	0	0.75	0.55	0.25
	40-70	8.17	0.28	30.6	0.80	0.25	0.35	0.09	0	0.70	0.50	0.29

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Table 5. Chemical properties of Edko soil.

Soil profile No.	Soil layer depth cm	PH, 1:2.5	EC (1:5) dS/m	$CaCO_3$ %	Cations (meq / 100 g soil)				Anions (meq / 100 g soil)		
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	CL^{-}	SO_4^{--}
1	0-25	8.11	0.61	1.80	0.86	0.45	1.50	0.25	0.80	1.8	0.46
	25-50	7.98	0.46	2.05	0.70	0.35	1.40	0.15	0.65	1.2	0.75
	50-90	8.16	0.69	2.06	0.90	0.60	1.55	0.30	0.95	1.75	0.65
2	0-25	8.19	0.68	1.10	0.85	0.59	1.61	0.35	0.85	1.90	0.65
	25-50	8.00	0.60	1.15	0.74	0.56	1.46	0.20	0.65	1.76	0.55
	50-90	8.26	0.75	1.20	0.95	0.60	1.70	0.40	1.00	2.00	0.65
3	0-25	8.00	0.59	1.00	0.65	0.45	1.55	0.25	0.65	1.50	0.75
	25-50	7.96	0.55	1.05	0.70	0.55	1.30	0.20	0.65	1.30	0.80
	50-90	8.03	0.67	1.11	0.85	0.60	1.55	0.30	0.80	1.55	0.95

Table 6. Physical and hydrophysical properties of Edko soil.

Soil profile No.	Soil layer depth cm	Partcle size distribution			Texture class	P_b g/cm^3	Vol. sat. φ	θ_v at different tensions (mbar)*					
		Sand %	Silt %	Clay %				100	330	1000	5000	8000	15000
1	0-25	34.6	10.65	54.75	Clay	1.30	0.5094	0.4885	0.4465	0.3910	0.3454	0.3050	0.2360
	25-50	55.6	16.76	27.64	Clay	1.55	0.4151	0.3690	0.3285	0.2760	0.2477	0.2016	0.1695
	50-90	38.6	12.50	48.90	Clay	1.38	0.4792	0.4565	0.3991	0.3528	0.3108	0.2885	0.2150
2	0-25	36.0	9.80	54.2	Clay	1.31	0.5067	0.4676	0.4022	0.3600	0.3350	0.3109	0.2391
	25-50	57.3	15.5	27.20	Clay	1.56	0.4113	0.3150	0.2760	0.2498	0.2205	0.2012	0.1785
	50-90	39.9	10.56	49.54	Clay	1.40	0.4717	0.4500	0.4005	0.3650	0.3033	0.2716	0.2150
3	0-25	41.1	10.95	47.95	Clay	1.40	0.4717	0.4545	0.4108	0.3615	0.3221	0.2928	0.2238
	25-50	61.6	13.82	24.58	Sandy Clay	1.67	0.3698	0.2995	0.2705	0.2309	0.2105	0.855	0.1505
	50-90	43.9	12.0	44.10	Clay	1.40	0.4717	0.4400	0.3913	0.3416	0.3004	0.2699	0.2075

RESULTS AND DISCUSSION

The inflection point (A) of the soil moisture-retention curve of Edko soil (taken as an example) is shown in Figs, 1 and 2. This inflection point separates the regions of macropore and micropore effects. θ_r was taken at 15000 mbar.The convexity in the soil moisture retention curve (Fig. 1) results from macropore effect, whereas the concavity reflects micropore effect. Therefore, the point (A) on the curve represents, in fact, the field capacity of the soil. The micropore effect (capillary effect) starts at point (A), and continues thereafter throughout the remainder of the curve.

The main chemical properties of the three tested soils are given in Tables 1, 3 and 5 for Nubaria, Borg El-Arab and Edko soils; respectively. Tables 2, 4 and 6 display the physical and hydrophysical properties of the three soils in the same order. These Tables contain a wide range of soil characteristics (CaCO3 content from 1 to 39%; $EC_{1:5\ extract}$ from 0.22 to 0.75 dS/m; Sand from 34.4 to 93 %; Soil bulk density from 1.3 to 1.8 g/cm^3 and the soil texture from sandy to clayey). The differentiation in these soil characteristics had been effect on the soil moisture retention data, which are used to estimate soil field capacity and its associated soil matric potential and soil pore diameter.

Data in Tables 7, 8, and 9 include the five parameters of soil moisture retention curve, which are used in van Genuchten's model (1980). These parameters were used in equations 2, 6, and 9 to estimate the field capacity (θ_{FC}). The Tables include also soil matric suction values at field capacity (h_{FC}) in mbar, as well as the water-filled soil pore diameters at field capacity in micrometers ($d\mu$). As presented in Table 7, θ_{FC} of the Nubaria soil ranged from 0.1959 to 0.2502 and the corresponding tension values, h_{FC} ranged from 30.66 to 106.24 mbar. The associated effective pore size, $d\mu$ ranged from 28.24 to 97.84 microns.The values of the three parameters θ_{FC}, h_{FC} and $d\mu$ for Borg El Arab soil (Table 8) ranged from 0.2180 to 0.2490, 156 to 220 mbar, and 14 to 19 microns; respectively.

These results indicate that the soil field capacity of these two calcareous soils is markedly low, which is – in part - attributed to the presence of calcium carbonates (Tables 2 and 4), in addition to the obvious effect of the coarse texture of these two soils. The coating effect of calcium carbonates on the soil particles results in reducing the water holding capacity of the soil matter (Hassan, 1960). The texture class of the Nubaria soil ranges from loamy sand to sand (Table 2) and that for Borg El Arab soil is loamy sand, (Table 4) for all layers of all profiles.

The soil matric suction in the Nubaria soil is lower than that of Borg El Arab soil. This is obviously due to the lighter texture (more sandy) of the Nubaria soil in comparison with the Borg El Arab soils, (Tables 2 and 4). Additionally, the fact that the diameters of effective soil pores (water-filled pores at field capacity) in the Nubaria soils are larger than in Borg El Arab content relationship as determined from equation 12 [Edko soil taken as an example, soil layer 0-25 cm]
soils appear to reflect, once again, the effect of the sandier texture of the former.

Table 9 shows that θ_{FC} of the Edko soil ranged from 0.2797 to 0.4177, h_{FC} ranged from 112 to 461 mbar and $d\mu$ ranged from 7 to 27 microns. These results appear consistent, and reflect- as expected- the clayey nature of the Edko soil. As shown in Table 7, all field capacity values determined for different samples of this soil were at soil moisture contents that corresponded to soil water potential values ranging from –0.1 to –0.5 bar. This observation agrees with conclusions suggested by Hadas (1973).

fig1,2

Table (7) Parameters of soil moisture retention curve used to calculate the field capacity and its associated parameters for the Nubaria soil.

Soil sample	φ	θr	α	n	m	h_{FC}	dμ	θ_{FC}
1	0.3962	0.0750	0.0921	1.4452	0.3080	47.70616	62.88496	0.2356
2	0.3585	0.0717	0.1497	1.4364	0.2940	32.17723	93.23364	0.2151
3	0.3585	0.0700	0.1194	1.4679	0.3188	33.92810	88.42227	0.2143
4	0.3208	0.0710	0.0848	1.4858	0.3270	45.06124	66.57606	0.1959
5	0.3774	0.0685	0.0713	1.4189	0.2952	68.36914	43.87945	0.2230
6	0.3962	0.0610	0.0287	1.6280	0.3834	94.75848	31.65944	0.2286
7	0.3962	0.0633	0.1101	1.5286	0.3458	30.66152	97.84251	0.2298
8	0.4151	0.0500	0.1112	1.5046	0.3354	32.45942	92.42309	0.2326
9	0.4340	0.0664	0.0355	1.4900	0.3289	106.2356	28.23913	0.2502
10	0.4261	0.0611	0.0358	1.5167	0.3407	97.39807	30.80143	0.2436
11	0.3962	0.0605	0.0554	1.4052	0.2884	93.32789	32.14473	0.2284
12	0.3962	0.0700	0.1067	1.3527	0.2607	63.40889	47.31198	0.2331
Average	0.3893	0.0657	0.0834	1.4733	0.3189	62.1243	59.6182	0.2275

Table (8). Parameters of soil moisture retention curve used to calculate the field capacity and its associated parameters for Borg El-Arab soil.

Soil sample	φ	θr	α	n	m	h_{FC}	dμ	θ_{FC}
1	0.4491	0.0551	0.0146	1.5511	0.3529	220.4307	13.60972	0.2521
2	0.4415	0.0563	0.0168	1.5463	0.3533	191.9397	15.62991	0.2489
3	0.4415	0.0564	0.0224	1.5176	0.3411	155.2666	19.3216	0.2490
4	0.4340	0.0535	0.0142	1.5612	0.3595	218.9526	13.7016	0.2438
5	0.4151	0.0587	0.0186	1.5809	0.3674	159.8127	18.77198	0.2369
6	0.3962	0.0398	0.0188	1.5112	0.3383	188.372	15.92593	0.2180
7	0.4151	0.0545	0.0156	1.5612	0.3595	198.9204	15.08141	0.2348
8	0.4075	0.0600	0.0135	1.6687	0.4007	185.5381	16.16919	0.2338
9	0.4000	0.0495	0.0178	1.628	0.3761	156.4100	19.18036	0.2248
Average	0.4222	0.0538	0.0169	1.5696	0.3610	186.1825	16.3769	0.2380

Table (9). Parameters of soil moisture retention curve used to calculate the field capacity and its associated parameters for Edko soil.

soil sample	φ	θr	α	n	m	h_{FC}	dμ	θ_{FC}
1	0.5094	0.326	0.0117	1.3961	0.2837	460.8684	6.509451	0.4177
2	0.4151	0.2142	0.0168	1.3969	0.2841	319.7886	9.381197	0.3147
3	0.4792	0.2805	0.0130	1.3857	0.2783	436.0609	6.879773	0.3799
4	0.50571	0.3011	0.0113	1.4509	0.3108	380.5736	7.882837	0.4034
5	0.4003	0.2002	0.0523	1.3642	0.2770	112.4396	26.68100	0.3003
6	0.4717	0.3012	0.0141	1.3874	0.2687	430.1316	6.974609	0.3865
7	0.4717	0.3200	0.0118	1.5600	0.7375	112.6805	26.62395	0.3959
8	0.3698	0.1896	0.0311	1.5034	0.3348	116.5077	25.74936	0.2797
9	0.4679	0.2750	0.0135	1.3927	0.282	405.7345	7.393998	0.3715
Average	0.4545	0.2675	0.0195	1.4264	0.3397	308.3095	13.78620	0.3610

Fig. (3a, b and c) includes three plots that describe the main field capacity trends and the associated soil matric suction as well as diameters of water-filled soil pores). The first Figure illustrates the average calculated field capacity values of the three soils. The two sandy calcareous soils (Nubaria and Borg El-Arab) have nearly the same value of field capacity, 0.2276 and 0.2380; respectively. These two values are significantly lower than that of the clayey Edko soils (0.3610) as discussed earlier. The second plot of Fig (3) illustrates the soil matric potential values associated with field capacity for the three soils. The values clearly increase as the soil texture becomes finer, being lowest for the Nubaria soil, intermediate for the Borg-El-Arab soil and greatest for the Edko soil (62, 188 and 308 mbar for the three soils, in respective order). This pattern is consistent with the fact that the fine soil particles, in fine-textured soils, have high soil moisture suction (high negative matric potential) due to capillary and surface forces, while coarse particles, in coarse-textured soils, have low soil moisture suction. The third plot of Fig. 3 displays the diameters of the water-filled capillary pores, associated with field capacity for the three soils. These values are approximately 80, 16 and 14 microns for Nubaria, Borg El–Arab and Edko soils; respectively. This trend clearly reflects the effect of soil texture, and hence the soil pore size distribution of these soils. Borg El–Arab soil has a medium soil texture and its pore size appears somewhat smaller than expected, even though it still falls between the values obtained for the other two soils. The small pore size value obtained for Edko soil reflects, as discussed above, its heavy (clayey) soil texture and finer soil pores.

fig3a

fig3b,c

Mathematical Correlation of Field capacity to Associated Soil arameters

From the above discussion, the fact that the soil field capacity increases with the increase of the finer fraction of the soil matter and decreases with the increase of coarser fraction is substantiated. To further describe this association, the correlation between values of field capacity and characteristics such as the bulk density, the total porosity, as well as sand and clay fraction percentages was examined.

Table 10 presents the different correlations between field capacity and the above physical characteristics for each of the three soils.

An oposite relationship between soil field capacity and soil bulk density is shown in (Fig. 4). Typically, high bulk density is associated with high sand content. High correlation coefficients were seen for all three soils.

Soil field capacity values were significantly correlated with total porosity with a determination coefficients ranging between approximately 0.95 and 0.97as shown in Fig. 5.

Table 10. Correlation of field capacity to some soil physical properties of the Nubaria, Borg El-Arab, and Edko soils.

Soil	Soil parameter	Correlated function	R^2
Nubarria	ρ_b, g/cm^3	$F.C = -0.1721\ \rho_b + 0.5064$	1.0000
	φ	$F.C = 0.463\ \varphi^{0.7527}$	0.9627
Borg El- Arab	ρ_b, g/cm^3	$F.C = -19.12\ \rho_b^3 + 86.867\rho_b^2 - 131.61\rho_b + 66.857$	0.9879
	φ	$F.C = 0.5773\ \varphi^{1.0279}$	0.9493
Idco	ρ_b, g/cm^3	$F.C = 4.0105\ \rho_b^3 - 17.734\ \rho_b^2 + 25.649\ \rho_b - 11.766$	0.9715
	φ	$F.C = 0.9989\ \varphi^{1.2934}$	0.9739
	Sand %, s	$F.C = -0.0049\ s + 0.5846$	0.9760
	Clay %, c	$F.C = 0.004\ c + 0.5846$	0.9719

The correlations between the field capacity of the clayey Edko soil and either sand or clay content were examined. High correlation coefficients were observed (Table 10 and Fig. 6). A somewhat similar relation between the field capacity and each of the sand and clay percentages was seen in the case of the other two soils. The correlations were not, however, as significant.

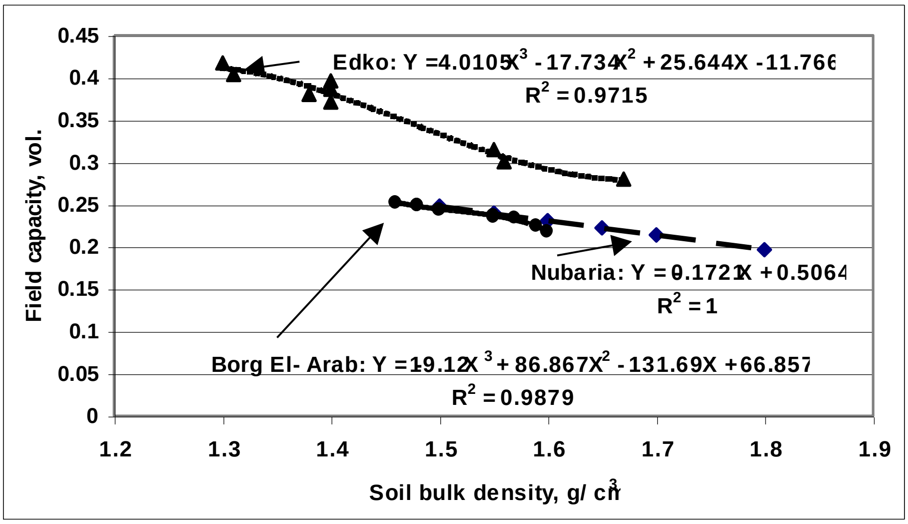

Fig.4. Correlations between soil bulk density and field capacity for Nubaria, Borg El- Arab and Edko soils

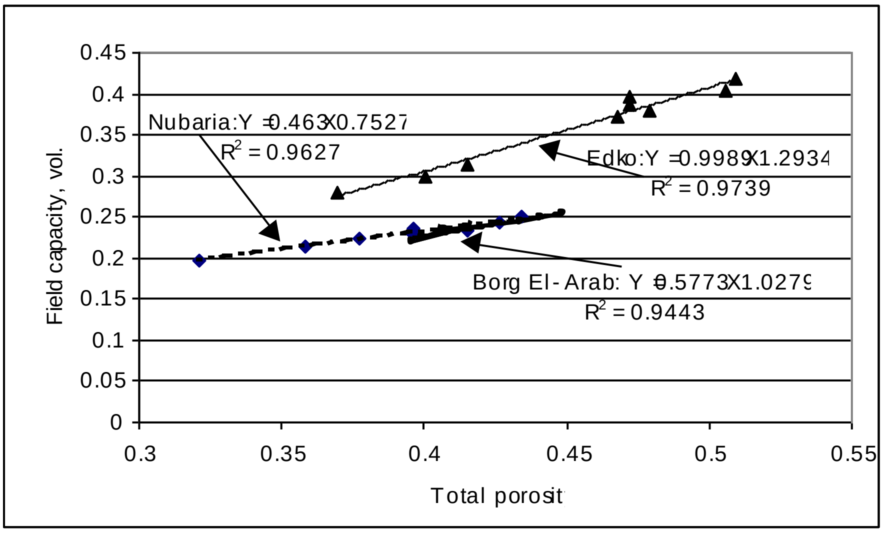

Fig.5. Correlations between total porosity and field capacity for Nubaria, Borg El- Arab and Edko soils

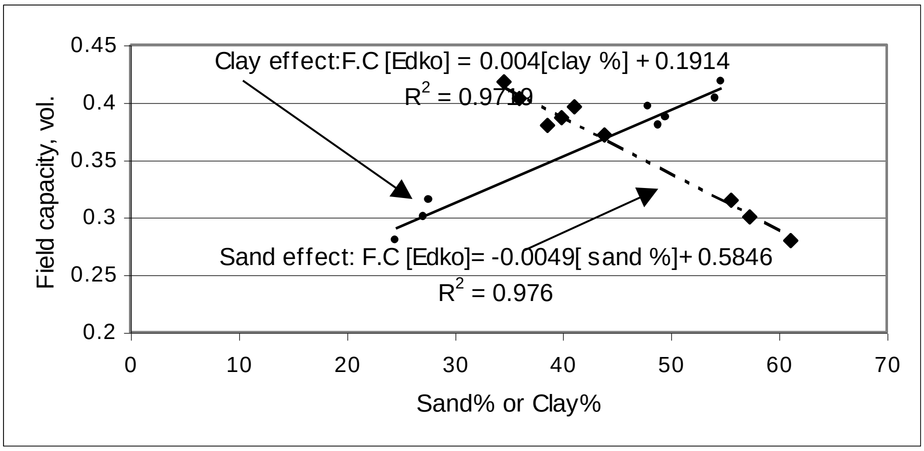

Fig.6. Correlation between sand and clay contents and estimated field capacity of Edko soil

The effect of the soil texture on the field capacity can perhaps be inferred most closely through the effect of the bulk density. Fig. 7 illustrates the general trend of the effect of soil bulk density on field capacity. The data used to construct the relationship shown in the Figure represents 30 soil samples taken from the three soil profiles of the examined soils. This correlation was very strong, with a correlation coefficient, r = 0.80*** and a determination coefficient of approximately 0.73, which reflects a marked effect. The tabulated correlation coefficient at P(0.01) was 0.463 at degree of freedom = 28. This, therefore, re-affirms the importance of giving a special consideration to the bulk density as a major criterion in defining or estimating the soil field capacity. This, in any case, is consistent with the commonly followed practical determination approaches.

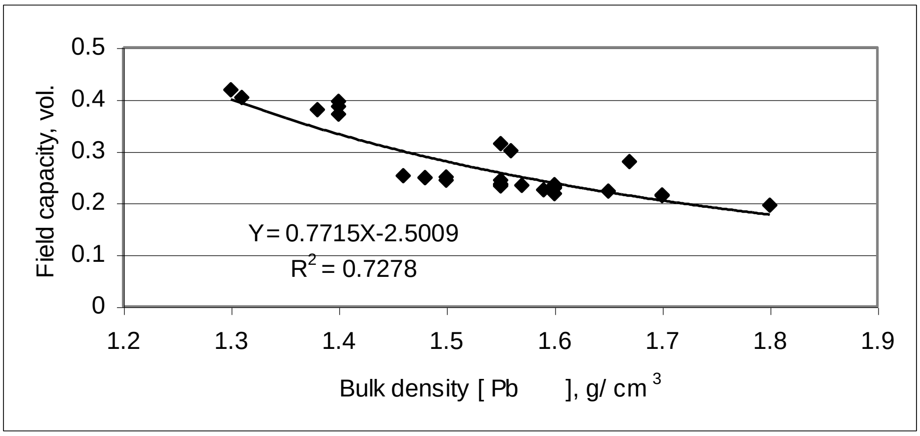

Fig. 7. General trand of soil bulk density effect on field capacity- all samples from all soils

CONCLUSION

The results reported in this study showed that it is feasible to calculate the soil field capacity and its associated parameters from the five parameters of the soil moisture retention model of van Genuchten and the capillary rise equation. Very simple measurements based on soil moisture retention curve appear to provide sufficient variables for calculating the various functions.

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تقدير دقيق للسعة الحقلية للتربة على أساس جهد مادة الارض واقطار المسام

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يهدف هذا البحث إلى تقدير السعة الحقلية تقديرا نوعياً (أي خاصاً بأرض معينة)، دقيقاً، وكذلك تحديد قيم كل من جهد مادة الأرض وأقطار مسام التربة المرتبطين بها، من خلال استخدام العلاقات الخاصة المميزة التي تربط بين المحتوى الرطوبي الأرضي وجهد مادة الأرض وأحجام المسام الأرضية . وترجع أهمية هذا العمل إلى أنه يتيح التقدير الفعلي للسعة الحقلية لأرض معينة بدلاً من استخدام القيمة المرتبطة نمطيا بمقادير من الجهد الرطوبي تتراوح بين نحو ٠,١ و ٠,٣ بار.

وتعتمد هذه الطريقة على تعيين نقطة الانقلاب inflection point على نموذج فان جنختن van Gneuchten لمنحنى الشد الرطوبي الأرضي الواسع الاستخدام وكذلك العلاقة بين جهد مادة الأرض وأحجام المسام الأرضية .

وفي هذا العمل أُخذت عينات أرضية من ثلاثة مواقع مختلفة بشمال مصر تمثل أراضى الاستصلاح الجديدة، بواقع ثلاثة قطاعات أرضية لكل موقع. هذه المواقع تشمل مناطق النوبارية وبرج العرب وادكو، وهي مناطق تتباين في صفاتها الفيزيائية لاسيما القوام texture .

وقد أوضحت النتائج أن قيم المحتويات الرطوبية الحجمية للسعة الحقلية الخاصة والمميزة لهذه الأراضي كانت في المتوسط ٠,٢٢٧٥ ، ٠,٢٣٨٠، ٠,٣٦١٠ لأراضى النوبارية وبرج العرب وإدكو على الترتيب. كما بلغت قيم الشد الرطوبي المرتبطة بقيم السعة الحقلية المقاسة لهذه الأراضي نحو ٦٢، ١٨٦، ٣٠٨ ملي بار.، وأقطار المسام الأرضية المملوءة بالماء عند السعة الحقلية لهذه الأراضي، وبنفس الترتيب، ٦٠، ١٤، ١٦ ميكرون.

وقد أوضح الفحص الإحصائي لارتباطات السعة الحقلية ببعض الخواص الفيزيائية الهامة المميزة للتربة درجات عالية من الارتباط، انعكست في معامل التقدير المرتفع ومعامل الارتباط عالي المعنوية.

Table 4. Physical and hydrophysical properties of Borg-El Arab soil.

Soil prof. No.	Soil layer depth cm.	Particle size distribution			Texture class	O.M. %	B.D g/cm^3	Vol. Sat φ	θ_V at different tensions (mbar)						
		Sand %	silt %	Clay %					100	330	1000	3000	5000	8000	15000
1	0 –20	72.33	17.30	9.37	L.Sand	0.65	1.46	0.4491	0.3660	0.2318	0.1423	0.1162	0.0932	0.0812	0.0551
	20-40	73.32	15.30	11.38	L.Sand	0.33	1.48	0.4415	0.3520	0.2011	0.1405	0.1060	0.0899	0.0795	0.0563
	40-70	79.91	13.00	7.90	L.Sand	0.30	1.48	0.4415	0.3195	0.1829	0.1365	0.0975	0.0811	0.0700	0.0564
2	0 –20	73.59	15.80	10.61	L.Sand	0.52	1.50	0.4340	0.3585	0.2210	0.1371	0.0981	0.0800	0.0725	0.0535
	20-40	80.82	11.80	7.38	L.Sand	0.30	1.55	0.4151	0.3075	0.1822	0.1239	0.0911	0.0809	0.0715	0.0587
	40-70	81.33	10.40	6.27	L.Sand	0.30	1.60	0.3962	0.2999	0.1779	0.1200	0.0900	0.0762	0.0650	0.0398
3	0 –20	80.92	10.70	8.38	L.Sand	0.45	1.55	0.4151	0.3335	0.1999	0.1311	0.0995	0.0785	0.0700	0.0545
	20-40	82.80	10.82	8.27	L.Sand	0.20	1.57	0.4075	0.3056	0.1698	0.1259	0.0975	0.0810	0.0795	0.0600
	40-70	83.38	9.82	6.80	L.Sand	0.20	1.59	0.4000	0.2997	0.1670	0.1120	0.0895	0.0715	0.0635	0.0495

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