

## Soil moisture adsorption capacity and specific surface area in relation to water vapor pressure in arid and tropical soils

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### Abstract

This study is devoted to predict water vapour adsorption and hydro-physical properties of arid soils in middle Nile Delta (Farm of the Faculty of Agriculture, Shebin El-Kom, Egypt) and of tropical soils (Felix and INIAP Farms) in Quevedo zone, Los Rios, Ecuador. The vapour pressure and isothermal adsorption of water vapour is used to predict soil moisture adsorption capacity ( $W_a$ ) and the specific surface area. To achieve these objectives, four soil profiles at different depths were investigated to indicate the status of hydro-physical properties of the studied area. The 1<sup>st</sup> & 2<sup>nd</sup> profiles are sandy loam (Felix Farm) and clay loam soils (Shebin El-Kom Farm), and 3<sup>rd</sup> & 4<sup>th</sup> are clay soils (INIAP Farm). Data of soil-water adsorption ( $W\%$ ) at different relative vapor pressures  $P/P_o$  are obtained for the studied soil profiles, where the  $W\%$  values increased with increasing  $P/P_o$  from 1.87% to 10.01% in the 1<sup>st</sup> and 2<sup>nd</sup> sandy loam and clay loam soil profiles, and reached 27.44% in the 4<sup>th</sup> clay soil profile. The highest values of water adsorption capacity ( $W_a$ ) were observed in the clay depths of 60 – 90 cm and 90 – 120 cm (INIAP-soil profiles) while the lowest values were in the subsurface depth (30 – 60 cm) of soil profiles 1<sup>st</sup> and 2<sup>nd</sup>. The other hydro-physical properties such as adsorbed layers and maximum hygroscopic water were obtained. The specific surface area ( $S$ ) in sandy loam 1<sup>st</sup>&2<sup>nd</sup> soil profiles is ranged from 113m<sup>2</sup>/g to 187m<sup>2</sup>/g and raised to 385m<sup>2</sup>/g and 553m<sup>2</sup>/g in the 3<sup>rd</sup> & 4<sup>th</sup> clay soil profiles. The corresponded values of the external specific surface area ( $S_e$ ) ranged from 42m<sup>2</sup>/g to 98m<sup>2</sup>/g and 74 m<sup>2</sup>/g to 252 m<sup>2</sup>/g respectively. Two equations were assumed (1) to predict  $P/P_o$  at water adsorption capacity ( $W_a$ ), and (2) to apply  $W_a$  in prediction of soil moisture retention i.e.,  $\psi(W)$  function at  $pF < 4.5$ .

**Keywords:** Water adsorption capacity, vapor pressure isotherm, soil hydro-physical properties, specific surface area, arid and tropical soils.

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### Introduction

Agricultural and irrigation management practices, is largely depend on a timely and accurate characterization of temporal and spatial soil moisture dynamics in the root zone (Han, 2011). Consequently, measurements and detailed information about soil water sorption, water content and behavior are required. In that connection, water vapor adsorption is an important phenomenon in particular in drying periods in tropical soils as well as in arid and semi-arid regions (Amer, 2014) at which the high temperature and dry weather supports to more evapo-transpiration. Water vapor either reaches the soil from the atmosphere or is formed in the soil by the evaporation of water. The migration of water vapor in soil depends not only on the difference of vapor pressure in different sites but also on the capacity of soil particles surfaces to attract and absorb the molecules of vapor. A gain of water in the soil surface layer, not caused by rainfall or irrigation, can be caused by dew deposition or vapor adsorption. Dew deposition is a phenomenon recorded for most soil and climate types (Jacobs et al., 1999). It occurs during the night when dew point is reached, and it results in a discernible wetting of the surface.

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Under the right atmospheric and soil surface conditions, water is adsorbed from the atmosphere by a thin layer of top soil, generally during the afternoon and evening. The amounts of adsorbed water can be considerable up to 70% of daily evaporation (Kosmas et al. 1998, 2001; Agam and Berliner, 2004). Therefore, quantifying adsorption is important for agricultural water management, surface energy balance studies, ecological studies (Levy and Mamedov, 2002), and remote sensing investigations (changes in surface soil moisture content will affect land surface properties such as albedo, emissivity, and thermal inertia).

The objective of this work is devoted to study the isothermal adsorption of water vapour at different vapour pressures as applied to predict soil-water adsorption capacity, specific surface area, and hygro-physical properties in semiarid soils in the Nile Delta (Egypt) and in the tropical soils of Quevedo region-Los Rios Province, Ecuador.

## Material and Methods

Four soil profiles differ in their particles size distribution, salinity, and  $\text{CaCO}_3\%$  were done in arid and tropical zones. Three tropical soil profiles (I, III, IV) were selected at different distances to Quevedo city, to represent the Quevedo region of the Los Rios Province, Ecuador. The investigated soils were cultivated mainly with Cacao, Banana and Corn crops. The arid soil profile No. II was taken from the Farm of Faculty of Agriculture, Menoufia University, Shebin El-Kom, (located at the Middle of the Nile Delta), Egypt. The profiles of Quevedo area is elevated 74m (243ft) above sea level and located at coordinates  $1^\circ 20' 30''$  de latitude south and  $79^\circ 28' 30''$  de longitude occidental, dentro de una zona subtropical (Figure 1). The first profile (I) was taken from the Felix Farm, which is located as far as 30 km from Quevedo city and cultivated with Cacao trees. The third and fourth profiles were taken from the INIAP Experimental Farms, Pichilingue, which located at 6 km to Quevedo. They were cultivated with Cacao and Corn crops respectively.

Disturbed and undisturbed soil samples were taken at depths, 0 – 30 cm, 30-60 cm, 60 - 90 cm for the first and second profiles, and 0 – 30 cm, 30 - 60 cm, 60 - 90 cm, 90 - 110 cm and 110 - 130 cm for the third profile and 0 – 30 cm, 30 - 60 cm, 60-90 cm, and 90 - 120 cm for the fourth one. The disturbed soil samples were air dried, gently crushed and sieved through a 2 mm sieve. Fractions below 2 mm were subjected to chemical and mechanical analysis in the laboratory. Soil texture (particle size distribution) was determined using the pipette method. The textural grade was assessed by texture triangle.

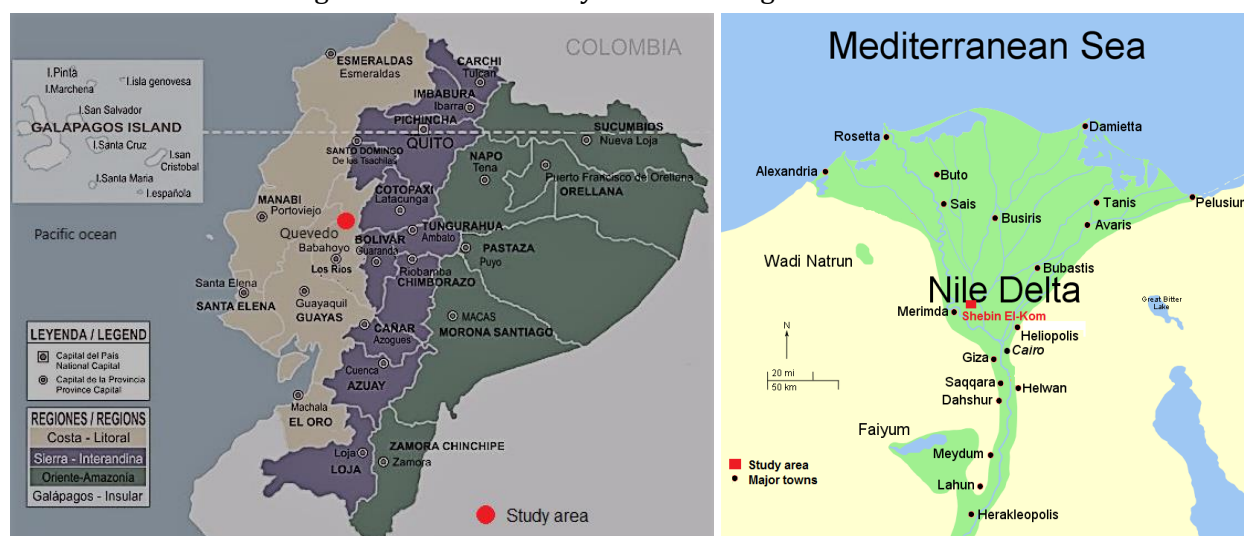


Figure1. Study areas (red color) in Los Rios province, Quevedo, Ecuador and in Nile Delta, Shebin El-Kom, Menoufia, Egypt

Physical and chemical analyses of the studied soils such as maximum hygroscopic water ( $MH$ ), Particle size distribution %, EC, OM,  $\text{CaCO}_3\%$  are determined according to Black et al. (1965) and Klute (1986). These analyses are shown in Tables 1 and 2.

Table 1. Particle size distribution of the studied soils

Profile Number & Soil location	Coarse Sand, %	Fine Sand, %	Silt, %	Clay, %	Texture Class
I- Felix Farm	38.50	20.50	24.10	16.90	Sandy Loam
II- Shebin El-Kom	15.76	18.35	27.32	38.57	Clay Loam
III-INIAP-Cacao Field	1.98	16.42	36.78	44.82	Clay
IV-INIAP-Corn Field	3.15	14.40	33.86	48.59	Clay

Table 2. Chemical analysis (mean values) of the studied soil profiles.

Chemical properties	Felix Farm	Shebin El-Kom Farm	INIAP-Cacao Field	INIAP-Corn Field
pH	6.82	6.85	7.24	6.91
EC (dS/m)	0.73	1.24	1.10	1.96
Ca <sup>2+</sup>	1.35	2.67	4.80	6.24
Mg <sup>2+</sup>	1.40	2.23	1.92	2.88
Na <sup>+</sup>	1.42	3.54	3.98	9.24
K <sup>+</sup>	0.13	0.39	0.48	1.48
CO <sub>3</sub> <sup>2-</sup>	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	3.40	3.93	2.25	2.85
Cl <sup>-</sup>	0.75	3.65	6.00	13.52
SO <sub>4</sub> <sup>2-</sup>	0.15	1.25	1.93	2.47
SAR	1.21	2.26	2.17	4.32
CaCO <sub>3</sub> (%)	1.12	3.42	0.43	0.34
OM (%)	1.38	2.21	2.72	2.99

### Water vapour adsorption isotherms

The water vapour adsorption isotherm on dried soils is determined gravimetrically using saturated salt solutions such as ZnCl<sub>2</sub>, CaCl<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>, NH<sub>4</sub>NO<sub>3</sub>, KCl and K<sub>2</sub>SO<sub>4</sub> whereas the corresponding P/P<sub>0</sub> values to these solutions at 20°C are 0.10, 0.35, 0.45, 0.65, 0.85 and 0.98 (Amer, 2009).

### Matric suction at water vapour pressures

The soil matric suction values resulting from equilibrating the soil samples with salt solutions can be calculated using the pF formula:

$$pF = 6.502 + \log [2 - \log H] \quad (1)$$

where,  $pF$  = soil suction, expressed as the common logarithm of the suction ( $\psi$ ) in cm of water,  $H$  is the relative humidity ( $H = P/P_0 \times 100$ ), and Relative water vapour pressure ( $P/P_0$ ) [ $P$  being the actual water vapour pressure on the sample particles and  $P_0$  being the saturation vapour pressure of water at 20°C] were obtained by applying different appropriate salt solutions.

### Moisture adsorption capacity

The property of moisture adsorption capacity ( $Wa$ ) can be introduced as the critical limit between adsorbed and absorbed wetting films (pellicles) of soil moisture content (Amer, 2003), as well as corresponds to capillary condensation. So, the  $Wa$  values can be also derived from soil moisture retention curve at  $\log(\psi_c)$  where  $\psi_c$  is the capillary condensation attitude.

Amer (1982, 1993) proved that the moisture adsorption capacity ( $Wa$ ) is equal to three layers of adsorbed water as follows:  $Wa = Wm + 2Wme$ , where  $Wm$  is the moisture of the soil when water vapour adsorbed for monolayer, and  $Wme$  is the external mono-adsorbed layer of soil moisture content.

However, the moisture adsorption capacity ( $Wa$ ), maximum hygroscopic water ( $MH$ ) the specific surface area ( $S$ ), and particle size composition are the most important indices characterizing the hydro-physical, physicochemical and heat properties of soil. Moreover, these parameters are inter-related, therefore the value of any of them can be obtained from the data of the other parameters.

### Estimating $Wm$ and $Wme$ for predicting the moisture adsorption capacity and surface area

The relation between relative vapour pressure ( $P/P_0$ ) and moisture content ( $W\%$ ) is experimental obtained by maintaining a soil sample in isothermal equilibrium with an atmosphere of water vapour as mentioned above.

The BET method (Brunauer et al., 1938) as modified and described by Orchiston (1954), Quirk (1955), Farrar (1963) and Globus (1996), was applied to predict the  $Wm$  and  $Wme$ , which they in turn were used to determine moisture adsorption capacity ( $Wa$ ) and the total, external and internal specific surface areas ( $S$ ,  $Se$  and  $Si$ ).

## Results and Discussion

### BET theory as applied for adsorption isotherms

Brunauer et al. (1938), derived what has come to be known as the BET equation, based on multilayer adsorption theory. In BET theory, the explanation proposed for sigmoid type isotherm is that the adsorption in multi-molecular layers on the surface rather than a monomolecular one. Farrar (1963) and Amer (1982, 1993, 2009) used the water vapour adsorption isotherm method by applying BET theory based on the

assumption that the isotherm is made up of monolayer physical adsorption combined with capillary condensation as follows:

$$P/V(P_o-P) = (1/V_m C) + (C-1) P/V_m C P_o \quad (2)$$

Where,  $V$  is the volume of gas adsorbed at pressure  $P$ ,  $V_m$  is the volume of a single layer of adsorbed molecules over the entire surface of the adsorbent (soil particles).  $P_o$  is the gas pressure required for monolayer saturation at the temperature of the experiment, and  $C$  is a constant for the particular gas, adsorbent, and temperature,

$$C = \exp E_i - E_L / RT \quad (3)$$

whereas,  $E_i$  is adsorption heat of the water adsorbed layer,  $E_L$  is condensation adsorption heat.

In this work we obtained experimentally and gravimetrically the relationship between relative vapour pressure ( $P/P_o$ ) and adsorbed moisture content,  $W\%$  (wetting films) on soil particles which depending on the thermodynamic of adsorption of water vapor through the soil. Data for water vapor adsorption at  $P/P_o$ ; 0.10, 0.35, 0.45, 0.65, 0.85, and 0.98 for the studied soils are presented in Table 3. It is evident that the  $W\%$  at different values of  $P/P_o$  was higher in both clay soil profiles (III & IV) of INIAP Farms –in particular in the deeper depths (60-90 cm and 90-120 cm) of the 4<sup>th</sup> soil profile- than in the other two sandy loam and clay loam soils (1<sup>st</sup> & 2<sup>nd</sup> profiles).

Table 3. Water adsorption ( $W\%$ ) in the studied soils at different vapor pressures ( $P/P_o$ ).

Soil location & Profile number	Soil Depth, cm	$P/P_o$ Soil water content,%	Soil water adsorption						
			0.10	0.35	0.45	0.65	0.85	0.98 (MH)	
Felix Farm I	0 - 30	10.285	1.918	4.469	5.020	5.489	5.590	7.640	
	30 - 60	8.359	1.874	4.241	4.790	5.031	5.372	6.955	
	60 - 90	20.540	2.679	6.527	7.068	7.592	8.061	10.01	
Shebin El-Kom II	0 - 30	19.120	2.689	6.423	6.980	7.322	7.873	9.878	
	30 -60	11.855	1.748	4.387	4.927	5.386	5.520	7.267	
	60 - 90	15.135	1.887	4.844	5.388	5.656	6.165	8.012	
INIAP-Cacao Field III	0 - 30	11.579	2.663	6.613	7.160	7.722	8.232	10.130	
	30 - 60	14.731	2.564	9.332	9.789	10.867	12.259	13.959	
	60 - 90	30.252	2.974	10.470	10.920	11.458	13.604	15.521	
	90 - 110	23.616	2.747	8.865	9.410	10.075	11.050	12.988	
	110 - 130	17.063	3.864	10.044	10.587	11.532	12.611	14.720	
INIAP-Corn Field IV	0 - 30	9.176	2.676	6.364	6.916	7.477	8.104	10.233	
	30 - 60	9.180	2.675	10.325	10.797	11.920	13.640	15.702	
	60 - 90	17.198	3.879	15.504	16.050	18.131	20.005	22.647	
	90 - 120	20.434	3.981	17.945	18.486	22.265	24.122	27.446	

The  $W\%$  values increased with increasing  $P/P_o$  from 1.87% to 10.01% in the 1<sup>st</sup> soil profile of sandy loam soil, and from 1.75% to 9.88% in the 2<sup>nd</sup> clay loam profile. In clay soils, the increasing of  $W\%$  values was from 2.56% to 15.52% in the 3<sup>rd</sup> soil profile, while it was more evident in the 4<sup>th</sup> profile where the increasing was from 2.67% to 27.44%. The clay content, mineralogical composition and salinity are the major factors that governed the absorbed water in the soils under investigation (Amer, 2009).

#### Solution of the BET equation for obtaining mono-adsorbed layers ( $W_m$ & $W_m e$ )

The BET equation can be applied in the following form using the gravimetric of a single layer of adsorbed molecules over the entire surface of the soil particles (Amer, 2009):

$$\frac{P}{W(P_o-P)} = \frac{1}{W_m C} + \frac{C-1}{W_m C} \cdot \frac{P}{P_o} \quad (4)$$

where  $W_m$  is the moisture content when the soil surface is completely covered by a mono-molecular layer of water.  $C$  is a function of the state of the first adsorbed molecular layer of water and soil particles surface condition.  $W$  is adsorbed soil moisture content (%) equilibrated with  $P/P_o$ , whereas  $P$  and  $P_o$  are the actual and saturated water vapor pressures. By plotting  $P/W(P_o-P)$  as ordinate versus  $P/P_o$  at the segment 0 – 0.40 of the sorption isotherm as abscissa, a straight line would be obtained. The intercept on the y-axis is then  $1/W_m C$  and the slope is  $C - 1/W_m C$ . Hence  $W_m$  and  $C$  can be determined.

Data for solution of BET equation are presented in Tables (4 and 5). From these data and linear equations, we can obtain  $W\%$  at any  $P/P_o$  values by using the next formula:

$$W = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[\frac{1}{WmC} + \frac{C-1}{WmC} \frac{P}{P_o}\right]} \tag{5}$$

To determine  $W_{me}$  the BET equation (4) can be developed with some assumptions to the next form:

$$W = \frac{Wme}{\left[1 - Ke \frac{P}{P_o}\right]} \cdot \frac{Ce}{Ce + \frac{P_o}{P} - Ke} + Wi \tag{6}$$

At high relative water vapor pressures, the amount  $Ce / (Ce + P_o/P - Ke)$  is equal unit (Farrar, 1963), and then the equation (6) becomes (Amer, 2015):

$$W = \frac{Wme}{\left[1 - Ke \frac{P}{P_o}\right]} + Wi \tag{7}$$

where the suffixes (e) and (i) refer to the external and internal surfaces respectively. The values of  $K_e$  in the indicated  $P/P_o$  range were stated by Farrar (1963) as  $0.9 \pm 0.01$ , but practically, it seems that  $K_e$  is an arbitrary coefficient ranged from 0.70 to 0.90 (Amer 1982, 2009). Equation (7) can be represented in linear equation;  $y = mx + c$  where  $y = W$ ,  $m = W_{me}$ ,  $x = 1 / 1 - K_e P/P_o$ , and  $c = Wi$ , so  $W_{me}$  can be obtained graphically as the intercept on the  $y$  - axis.

Values of  $Wm$  and  $Wme$  are calculated for the studied soils as in Table 6. It is found that the highest values of  $Wm$  and  $Wme$  were in the deeper depths of the clay soils (INIAP farms) in particular the depths of 60 – 90 cm and 90 – 120 cm of INIAP crop field (profile IV).

Table 4. Using Equation (5) in solution of the BET equation for sandy loam and clay loam soil profiles (I and II)

Soil location	Soil Depth, cm	$P/P_o$	0.10	0.20	0.30	0.35	$C$	Linear & adsorption equations
I Felix Farm	0 - 30	W%	1.920	3.200	4.050	4.470	7.472	$P/W(P_o-P)=0.036+0.233P/P_o$
		$W(1-P/P_o)$	1.728	2.560	2.835	2.905		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.036 + 0.233 \frac{P}{P_o}\right]}$
		$P/W(P_o-P)$	0.058	0.078	0.106	0.120		
	30 - 60	W%	1.874	3.000	3.800	4.241	10.238	$P/W(P_o-P)=0.03+0.277P/P_o$
		$W(1-P/P_o)$	1.687	2.400	2.660	2.758		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.03 + 0.277 \frac{P}{P_o}\right]}$
		$P/W(P_o-P)$	0.059	0.083	0.113	0.127		
60 - 90	W%	2.679	4.500	5.800	6.527	8.391	$P/W(P_o-P)=0.023+0.17P/P_o$	
	$W(1-P/P_o)$	2.411	3.600	4.060	4.243		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.023 + 0.17 \frac{P}{P_o}\right]}$	
	$P/W(P_o-P)$	0.042	0.056	0.074	0.083			
II Shebin El-Kom	0 - 30	W%	2.689	4.480	5.750	6.423	10.548	$P/W(P_o-P)=0.019+0.1814P/P_o$
		$W(1-P/P_o)$	2.420	3.584	4.025	4.175		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.019 + 0.1814 \frac{P}{P_o}\right]}$
		$P/W(P_o-P)$	0.037	0.055	0.074	0.083		
	30 - 60	W%	1.748	2.650	3.300	4.387	13.258	$P/W(P_o-P)=0.024+0.2942P/P_o$
		$W(1-P/P_o)$	1.573	2.120	2.310	2.851		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.024 + 0.2942 \frac{P}{P_o}\right]}$
		$P/W(P_o-P)$	0.064	0.094	0.129	0.126		
60 - 90	W%	1.887	3.400	4.560	4.844	11.324	$P/W(P_o-P)=0.03+0.2771P/P_o$	
	$W(1-P/P_o)$	1.698	2.720	3.192	3.149		$W\% = \frac{\frac{P}{P_o}}{\left[1 - \frac{P}{P_o}\right] \left[0.03 + 0.277 \frac{P}{P_o}\right]}$	
	$P/W(P_o-P)$	0.059	0.074	0.940	0.111			

**Soil specific surface area**

The specific surface of the adsorbent (soil) can be calculated by determining the number of molecules (volumetrically or gravimetrically) and multiplying this by the cross- sectional area of the molecules. Assuming that a single water molecule occupies some constant area on the sorbent surface (usually taken as  $10.8 \text{ \AA}^2$ ), the total specific surface area ( $S$ ) of the soil then calculated as  $S = 36.16 W_m \text{ m}^2/\text{g}$ .

Table 5. Using Equation (5) in solution of the BET equation for clay tropical soil profiles (III and IV).

Soil location	Soil Depth, cm	P/Po	0.10	0.20	0.30	0.35	C	Linear & adsorption equations
III INIAP- Cacao Field	0 - 30	W%	2.663	4.380	5.750	6.613	7.446	$P/W(Po-P)=0.025+0.1611P/Po$
		W(1-P/Po)	2.397	3.504	4.025	4.298		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.025 + 0.1611\frac{P}{Po}]}$
		P/W(Po-P)	0.042	0.057	0.075	0.081		
	30 - 60	W%	2.564	5.500	8.120	9.330	3.638	$P/W(Po-P)=0.03+0.0791P/Po$
		W(1-P/Po)	2.307	4.400	5.684	6.065		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.03 + 0.0791\frac{P}{Po}]}$
		P/W(Po-P)	0.043	0.046	0.053	0.058		
	60 - 90	W%	2.974	6.740	9.200	10.470	5.486	$P/W(Po-P)=0.02+0.0897P/Po$
		W(1-P/Po)	2.677	5.392	6.440	6.806		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.02 + 0.0897\frac{P}{Po}]}$
		P/W(Po-P)	0.037	0.037	0.047	0.051		
	90 - 110	W%	2.747	5.000	6.600	8.865	5.060	$P/W(Po-P)=0.028+0.1157P/Po$
		W(1-P/Po)	2.472	4.000	4.620	5.762		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.028 + 0.1157\frac{P}{Po}]}$
		P/W(Po-P)	0.040	0.050	0.064	0.061		
110 - 130	W%	3.864	6.200	8.510	10.044	2.929	$P/W(Po-P)=0.032+0.0617P/Po$	
	W(1-P/Po)	3.478	4.960	5.957	6.529		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.032 + 0.0617\frac{P}{Po}]}$	
	P/W(Po-P)	0.029	0.403	0.050	0.054			
IV INIAP- Corn Field	0 - 30	W%	2.680	4.120	5.500	6.364	5.937	$P/W(Po-P)=0.022+0.1864P/Po$
		W(1-P/Po)	2.408	3.296	3.850	4.137		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.022 + 0.1864\frac{P}{Po}]}$
		P/W(Po-P)	0.042	0.061	0.078	0.085		
	30 - 60	W%	2.675	5.880	8.750	10.325	3.245	$P/W(Po-P)=0.029+0.0655P/Po$
		W(1-P/Po)	2.408	4.704	6.125	6.711		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.029 + 0.0655\frac{P}{Po}]}$
		P/W(Po-P)	0.042	0.043	0.049	0.052		
	60 - 90	W%	3.879	10.000	13.800	15.504	6.481	$P/W(Po-P)=0.012+0.0652P/Po$
		W(1-P/Po)	3.491	8.000	9.660	10.078		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.012 + 0.0652\frac{P}{Po}]}$
		P/W(Po-P)	0.029	0.025	0.031	0.035		
	90 - 120	W%	3.981	11.500	16.320	17.945	5.937	$P/W(Po-P)=0.011+0.0543P/Po$
		W(1-P/Po)	3.583	9.200	11.424	11.664		$W\% = \frac{\frac{P}{Po}}{[1 - \frac{P}{Po}][0.011 + 0.0543\frac{P}{Po}]}$
		P/W(Po-P)	0.028	0.022	0.026	0.030		

Data in Table 6, which based upon the water vapor adsorption isotherms show that the specific surface area (S) in the light textured soils ranged from 117 m<sup>2</sup>/g to 187 m<sup>2</sup>/g in the first profile and from 113 m<sup>2</sup>/g to 180 m<sup>2</sup>/g in the second profile. In clay tropical soils, the S values were from 194 m<sup>2</sup>/g to 385 m<sup>2</sup>/g in the third profile and from 173 m<sup>2</sup>/g to 553 m<sup>2</sup>/g in the fourth profile. Farrar (1963) deduced the soil external specific surface area (Se) by applying the relation (6) over the range of high relative vapor pressure (0.5 < P/Po > 0.8). However, the internal specific surface area (Si) may be calculated by the difference between S and Se.

The corresponding values of Se (Table 6) were 46 m<sup>2</sup>/g to 98 m<sup>2</sup>/g and 42 m<sup>2</sup>/g to 93 m<sup>2</sup>/g in the 1<sup>st</sup> and 2<sup>nd</sup> soil profiles and from 77 m<sup>2</sup>/g to 165 m<sup>2</sup>/g and 74 m<sup>2</sup>/g to 252 m<sup>2</sup>/g in clay soil profiles. Regarding the internal specific surface area (Si), it was found in loam soils that Si values are higher than Se in the surface (0 – 30 cm) and subsurface (30 – 60 cm) depths of the 1<sup>st</sup> profile (Felix farm), while the same observation was in the depths 30 – 60 cm and 60 – 90 cm of the 2<sup>nd</sup> profile (dry soil). In clay soils (INIAP farms) the Si values were higher than Se in all depths of the 3<sup>rd</sup> and 4<sup>th</sup> profiles. The results reflect different due to the difference of the investigated soils in their texture, clay content%, CaCO<sub>3</sub>, salinity and mineralogical composition (El-Sharkawy, 1994; El-Fiky, 2002). However, the specific surface area is closely related to the physicochemical soil properties (Nerpin and Chudnovski, 1975), which is refer to the absence or presence of internal pores.

Whatever, the  $Se/Si$  ratio was less than unit in most depths of sandy loam soils and in all depths of the clay soils indicating that the  $Si$  values were higher than  $Se$  in most investigated tropical soils (Table 6). This result may refer to the mineralogical composition of these soils (Figure 2), whereas the montmorillonite, ferrous and hydrous mica are the prevailing minerals in the tropical soils as well as in the clay alluvial arid soils of the Nile Delta (El-Gabaly and Khadr, 1962).

Table 6. Water adsorption capacity ( $Wa$ ), adsorbed layers ( $Wm$  &  $Wme$ ) and specific surface area ( $S$ ,  $Se$  &  $Si$ ) of the studied soils.

Soil location	Soil Depth, cm	$Wm$	$Wme$	$Wc$	$Wa$	$[P/Po]_{wa}$	$S, m^2/g$	$Se, m^2/g$	$Si, m^2/g$	$Se/Si$	$Wa/S$
<b>I Felix Farm</b>	0 - 30	3.717	1.624	5.341	6.965	0.4662	134.430	58.72	75.710	0.775	0.0518
	30 - 60	3.256	1.274	4.530	5.804	0.4388	117.730	46.06	71.670	0.642	0.0493
	60 - 90	5.181	2.735	7.916	10.651	0.5135	187.350	98.89	88.460	1.117	0.0568
<b>II Shebin El-Kom</b>	0 - 30	4.989	2.581	7.570	10.151	0.5084	180.41	93.32	87.090	1.071	0.0562
	30 - 60	3.143	1.188	4.331	5.519	0.4306	113.64	42.95	70.690	0.607	0.0485
	60 - 90	3.222	1.248	4.470	5.718	0.4305	116.50	45.12	71.380	0.632	0.0491
<b>III INIAP-Cacao Field</b>	0 - 30	5.372	2.148	7.520	9.668	0.4442	194.25	77.67	116.58	0.666	0.0497
	30 - 60	9.160	3.964	13.124	17.088	0.4636	331.30	143.34	187.960	0.762	0.0515
	60 - 90	9.115	4.240	13.355	17.595	0.4819	329.58	153.32	176.260	0.869	0.0533
	90 - 110	6.934	2.773	9.707	12.480	0.4424	250.74	100.27	150.470	0.666	0.0498
	110 - 130	10.670	4.568	15.238	19.806	0.4612	385.85	165.18	220.670	0.748	0.0513
<b>IV INIAP-Corn Field</b>	0 - 30	4.798	2.067	6.865	8.932	0.4628	173.51	74.74	98.770	0.756	0.0515
	30 - 60	10.550	4.542	15.092	19.634	0.4610	381.54	164.23	217.310	0.755	0.0514
	60 - 90	12.965	5.837	18.802	24.639	0.4743	468.82	211.06	257.760	0.818	0.0525
	90 - 120	15.310	6.981	22.291	29.272	0.4768	553.63	252.43	301.190	0.838	0.0529



Figure 2. Clay soil samples were taken at depth >90 cm from INIAP research station- Pichilingue, Ecuador ~containing ferrous and ferric minerals with the highest values of surface area and water adsorption capacity (Amer, 2015).

### Soil moisture adsorption capacity

Due to the soil - water adsorption capacity ( $Wa$ ) is obeyed the mono-adsorbed layers ( $Wm$  &  $Wme$ ) values (whereas,  $Wa = Wm + 2Wme$ ), so it could be correlated with specific surface area. The  $Wa/S$  ratio was 0.0486 - 0.0568 for all the studied soils (Table 6). The values of  $Wa$  are the highest in the same deep depths, whereas  $Wa$  values in INIAP-profile IV reached 24.64% and 29.27% in the depths of 60 - 90 cm and 90 - 120 cm respectively, while reached 19.81% in the depth of 110 - 130 cm in the INIAP- profile III (Table 6). The high values of soil water adsorption capacity in the studied clay soils showed the importance of water adsorption phenomena in tropical soils.

The  $Wa$  values in the surface depth (0-30 cm) ranged from 6.97% to 10.15% in both sandy loam and clay loam soils under investigation. The lowest values for  $Wa$  were observed in the subsurface depth (30 - 60 cm) in soils profiles I and II, where, the  $Wa$  values were 5.80% and 5.52%, but increased to 17.09% and 19.63 in subsurface depth (30-60 cm) of the clay soil profiles III and IV respectively. This is indicated the significance of the soil texture and clay fraction content which play an important role in soil moisture content and its distribution along the soil profile depth. In general, high clay content in soil means increasing the soil moisture content & retention and water adsorption capacity. The same trend was ordinary observed with the other hygroscopic parameters such as boundary moisture films ( $Wc$ ) and maximum hygroscopic water ( $MH$ ). Hygroscopic water exists as a very thin film at the solid-liquid interfaces of the soil particles. At the maximum hygroscopic water ( $MH$ ) the surface of soil particles is almost completely covered with individual molecules of water. However, It is known that the maximum hygroscopic water ( $MH$ ) is determined practically at  $P/Po = 0.98$ . So, data in Table 3 indicate that the  $MH$  values (at  $P/Po = 0.98$ ) are ranged from 6.95% -10.01% in soil profiles I & II, and from 10.13% - 27.44%, for the clay soils (profiles III &

IV). It is clear that the hygro-physical properties ( $W_m$ ,  $W_{me}$ ,  $W_c$ ,  $W_a$  and  $MH$ ) of the investigated soils are followed the same trend that observed in turn with the specific surface areas ( $S$  and  $Se$ ).

### Predict of $P/P_o$ at water adsorption capacity ( $W_a$ )

At higher water vapor pressure ( $P$ ), the equation (4) can be developed to predict the vapor pressure  $P/P_o$  at water adsorption capacity  $W_a$  as follows:

$$\frac{\frac{P}{P_o}}{w(1-\frac{P}{P_o})} = A + B \frac{P}{P_o} \quad (8)$$

Where,  $A = 1/W_m C$ , and  $B = C-1/W_m C$

From equation (8) and at  $P_o/P \approx 1$ ;

$$W(1 - P/P_o) = 1 / (A + B) \quad (9)$$

Then at  $W_a$ ;

$$[P/P_o]_{w_a} = 1 - [W_a (A + B)]^{-1} \quad (10)$$

Data in table (6) show that the relative vapor pressure  $[P/P_o]_{w_a}$  at  $W_a$  is ranged between 0.43 to 0.51, indicating that at this range of  $P/P_o$  the soil moisture reach water adsorption capacity. Above this range ( $P/P_o > 0.51$ ) the absorption process is prevailing, at which soil matric suction ( $\psi$ ) values can be calculated using equation (1);  $pF = 6.502 + \log [2 - \log P/P_o]$ . The  $\psi$  values expressed in pF at adsorption and absorption processes are ranged from 4.5 to 7.0. On the other hand, it may of interest to apply the water adsorption capacity ( $W_a$ ) to predict soil moisture retention function  $\psi(W)$  at  $pF < 4.5$  using the following suggested equation:

$$\Psi_i = \psi_a (W_i - W_c / W_{me})^{-n} \quad (11)$$

where  $\psi_i$  and  $\psi_a$  are capillary-sorption potentials at soil water content ( $W_i$ ) and moisture adsorption capacity ( $W_a$ ), respectively, and  $n$  is a constant. The decrease in soil water suction is associated with increasing thickness of the hydration envelopes covering the soil particles surfaces (Amer, 2009).

## Conclusion

Soil-water adsorption  $W\%$  values increased with increasing  $P/P_o$  from 1.87% to 10.01% in the 1<sup>st</sup> and 2<sup>nd</sup> sandy loam and clay loam soil profiles, and reached 27.44% in the 4<sup>th</sup> clay tropical soil profile. The values of mono adsorbed layers ( $W_m$  &  $W_{me}$ ), boundary moisture films ( $W_c$ ), maximum hygroscopic water ( $MH$ ), water adsorption capacity ( $W_a$ ) and specific surface area ( $S$ ), external ( $Se$ ), internal ( $Si$ ) of the tropical soils in the Quevedo region area (Ecuador) and in semiarid region of the Nile Delta (Egypt) are obtained experimentally.

Water adsorption capacity ( $W_a$ ) is corresponding to  $P/P_o = 0.43 - 0.51$  for all soils under investigation. The absorption process is prevailing above this range.

The highest values of water adsorption capacity ( $W_a$ ) were observed in the clay depths of 60 – 90 cm and 90 – 120 cm (INIAP-soil profiles) while the lowest values were in the subsurface depth (30 – 60 cm) of soil profiles 1<sup>st</sup> and 2<sup>nd</sup>. The specific surface area ( $S$ ) in sandy loam & clay loam (1<sup>st</sup> & 2<sup>nd</sup> tropical and arid soil profiles) is ranged from 113m<sup>2</sup>/g to 187m<sup>2</sup>/g and raised to 385m<sup>2</sup>/g and 553m<sup>2</sup>/g in the 3<sup>rd</sup> & 4<sup>th</sup> clay tropical soil profiles. The corresponded values of the external specific surface area ( $Se$ ) ranged from 42m<sup>2</sup>/g to 98m<sup>2</sup>/g and 74 m<sup>2</sup>/g to 252 m<sup>2</sup>/g respectively.

The internal specific surface area ( $Si$ ) values were higher than the external specific surface area ( $Se$ ) in all depths of the clay soil profiles, while they were higher than  $Se$  in sandy loam and clay loam soils only in the subsurface (30 – 60 cm) depth.

The results of specific surface area ( $S$ ,  $Se$ ,  $Si$ ), mono adsorbed layers ( $W_m$  &  $W_{me}$ ), water adsorption capacity ( $W_a$ ) reflect different due to the texture and mineralogical composition of the investigated soils.

Clay soils at depth >90 cm in the farms of INIAP research station-Pichilingue, are containing ferrous and ferric minerals with the highest surface area and water adsorption capacity.

Results of soil water adsorption capacity show the significance of water adsorption capacity for moisture plant root zone – in particular- in clay soils.

Two new equations were assumed (1) to predict  $P/P_o$  at water adsorption capacity ( $W_a$ ), and (2) to predict the soil moisture retention function  $\psi(W)$  at  $pF < 4.5$ , depending on the water adsorption capacity  $W_a$ .



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