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Using effective moisture content to predict sorptivity

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Abstract

Background. Soil sorptivity is a critical hydraulic property governing early-stage infiltration though it is difficult to measure it directly in field conditions. Effective moisture content (Se) is a more accessible hydraulic parameter that may serve as a proxy.

Purpose. This study aimed to evaluate the potential of effective moisture content, measured at a tension of 336 cm water, to predict soil sorptivity across varying soil textures in semi-arid northern Iraq.

Materials and methods. Eight soil samples (sandy clay loam to clay) were collected from Nineveh Province. Effective moisture content was calculated from saturated and residual moisture measurements. Sorptivity was determined assuming both spherical and cubic aggregate geometries.

Results. Effective moisture content at 336 cm water showed a strong linear relationship with sorptivity ($R^2 = 0.94$ for spherical aggregates). Clay content was the dominant factor influencing both parameters. The spherical aggregate assumption produced higher and more representative sorptivity values compared to cubic geometry.

Keywords: effective moisture content; sorptivity; hydraulic functions; porous medium

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Introduction

It takes time and effort to accurately calculate the soil hydraulic function values. many attempts have been made to develop different methods for predicting a number of hydraulic functions, including effective moisture content. unsaturated hydraulic conductivity and water retention curve [1]. Most predic-

tion models are essentially based on assumptions about capillary medium characteristics and on the volumetric distribution of soil pores. These assumptions are widely accepted in theory and been found valid in practice. Various mathematical models have been used to describe the hydraulic functions of the soil [2-4]. Effective Moisture Content is one of the important hydraulic functions of the soil and is actually calculated using the following equation:

$$S_e = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} \quad (1)$$

where $\theta(h)$ = Moisture content at influencer tensions.

(θ_r, θ_s) = residual and saturated moisture content ($\text{cm}^3 \text{cm}^{-3}$).

Numerous attempts have been made to develop mathematical models to predict effective moisture content values (S_e), the most important of which is:

Brooks and Corey Model (1964)

It depends mainly on the air-entry value, and this model represents the basis for other mathematical models [5].

$$S_e = (\psi_e / \psi)^{-\lambda} \quad \psi < \psi_e \\ S_e = 1 \quad \psi \geq \psi_e \quad (2)$$

where S_e = predicted effective moisture content. ψ_e = air-entry value.

λ = is an empirical parameter often referred to as the pore size distribution index, ψ = matric potential at any point.

It should be indicated that the use of this model showed good results for predicting the water properties of the soil [6].

Van Genuchten Model (1980)

Being a closed-form analytical mathematical model developed from [5]. The model depending on the relationship between volumetric moisture content and tensions Therefore, it is called the moisture retention model [7]. It is considered one of the most important mathematical models for the moisture retention curve and he relied on it to develop numerical models and solutions and to use software to predict soil water characteristics as in the HYDRUS-1D to predict some soil hydraulic parameters [1; 2; 8].

$$\frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \frac{1}{[1 + (\alpha h)^n]^m} \quad (3)$$

The right side of the equation represents the predicted effective moisture content (S_e).

where h = soil water pressure (cm).

n and m are curve shape parameters of water retention. The parameter (α) is described as inverse of the pressure head at the point, it is a n value greater than (1), Either (m) value is related to (n) value and equal to ($m = \frac{1}{1 - n}$).

Modified Water Retention Equation (MWR)

The model was modified by [9;10] to obtain a modified water retention equation, to predict the moisture content in terms of tensions, the following formula is used:

$$\theta(h) = \theta_r + \frac{\theta_m - \theta_r}{[1 + |\alpha h|^n]^m} \quad h < h_s \quad (4)$$

$$\theta_s \quad h \geq h_s$$

where (θ_m) = represents an extension of the curve line as well as the theoretical basis for the modification of the equation. As the moisture content upon saturation (θ_s) , is replaced by an estimating factor, which is (θ_m) and always be $\theta_m > \theta_s$.

The most accurate result is in favour of (θ_m) .

$$S_e = \frac{\theta(h) - \theta_r}{\theta_m - \theta_r} \quad (5)$$

$$\theta_m = \theta_r + (\theta_s - \theta_r)(1 + |\alpha h_s|^n)^m \quad (6)$$

The effective moisture content was used to predict some hydraulic functions for soil [11], used the equations of [9;12]. To obtain a model for calculating the unsaturated hydraulic conductivity, as in the following model:

$$K(\theta) = K_0 S_e^L \left[1 - (1 - S_e^{1/m})^2 \right] \quad (7)$$

where $K(\theta)$ = unsaturated hydraulic conductivity, K_0 = saturated hydraulic conductivity, L = a constant related to the soil pores; imposed by Mualem by (0.5).

The MVG model is successful for describing water movement and runoff in an unsaturated condition, as well as the mathematical properties of the model to estimate the range of different soil textures, especially medium and coarse. Several attempts have been made to modify the model and make it more flexible, especially for fine textures with high clay content the modification of the model was when linking the modified water retention equation with the MVG model is obtained modified model MMVG as stated in [11].

$$K(S_e) = K_0 S_e^L \left[\frac{1 - F(S_e)}{1 - F(1)} \right]^2 \quad (8)$$

$$\text{Where } F(S_e) = [1 - (S_e)^{1/m}]^m \quad (9)$$

sorptivity depends on the initial moisture content (θ_o) , Since the value (S) ,

It is almost Non-existent when the initial moisture content reaches (θ_s) , The sorptivity is a function of the cumulative infiltration values [13].

$$I = S t^{0.5} \quad (10)$$

where I = Horizontal cumulative infiltration (cm).

S = sorptivity ($\text{cm min}^{-0.5}$).

The study *aims* to develop a new and easy method for measuring sorptivity. This is an important and difficult property to measure. Therefore, this research represents an innovative scientific method for measuring hydraulic functions in a simple way, which saves a lot of time and effort.

Materials and methods

Soil sample collection

Surface soil samples were collected at a depth of (0-30) cm. For eight sites with different textures, under various plant covers. It ranged from sandy clay loam to clayey, and from different regions in Nineveh province, northern Iraq. It is about by 222 meters above sea level and is considered among the arid and semi-arid area. The soil is calcareous and the largest group according to the American classification is Calciorthisds. Soil samples were taken to the laboratory aggregations were obtained through a sieve with a diameter of (9) mm, and it received the permeable part on a sieve of the diameter of its openings (4) mm, soil aggregate were taken and dried under laboratory conditions, soil samples were also obtained for the remainder of the soil after drying, grinding and passing it through a sieve with a diameter of (2) mm, to be ready for various physical and chemical analyzes.

Physical and chemical analyzes of the soil

Some chemical and physical properties were measured according to [14]. The volumetric distribution of soil particles was estimated using the hydrometer method, as stated in [15]. The bulk density was estimated using the core sample method using an open-ended metal cylinder with a height of (5) cm and a diameter of (4.5) cm, as stated in [16]. The electrical conductivity (EC) of soil and water extract (1:1) was measured using an EC-meter. The degree of reactivity of the soil pH was measured using a pH-meter and according to the method reported by [17]. The organic matter was quantified by the method of wet digestion and as stated in Walkely and Black cited in [18]. The soil content of total carbonates, positive ions and negative ions were estimated according to the methods described by [19]. Tables (1 and 2) show the results of the chemical and physical analyzes.

Table 1.

Some chemical properties of the soil study

Texture	Property				
	pH	EC dSm ⁻¹	Na exchanged	CEC	Total carbonate g kg ⁻¹
			Cmolc kg ⁻¹		
Clay	8.30	1.66	2.22	27	360
loam	7.65	2.10	3.70	23	260

Clay loam	8.11	0.45	0.75	26	330
Silty loam	7.67	3.12	3.90	28	275
Silty clay loam	7.80	1.30	2.05	29	305
Silty clay	8.22	0.68	0.92	31	380
Sandy clay	7.70	0.73	1.37	18	240
Sandy clay loam	7.78	0.82	1.65	16	255

Table 2.

Some physical properties of the soil study

Soil type	Order	Soil particle fractions gm. Kg ⁻¹			Bulk density Mg. m ⁻³	Total porosity cm.cm ⁻¹	Initial Volumetric water content cm.cm ⁻³	Hydraulic conductivity cm. hr ⁻¹	Soil Organic Matter gm. Kg ⁻¹
		Clay	silt	sand					
Clay	ARIDISOLS	560	300	140	1.17	0.558	0.24	0.075	20.55
loam	ENTISOLS	210	420	370	1.33	0.498	0.141	0.255	11.30
Clay loam	ENTISOLS	350	360	290	1.36	0.486	0.192	0.144	12.76
Silty loam	ARIDISOLS	200	640	160	1.30	0.509	0.183	0.200	10.63
Silty clay loam	ENTISOLS	330	515	155	1.34	0.494	0.190	0.104	8.40
Silty clay	ARIDISOLS	455	460	85	1.38	0.479	0.200	0.111	5.88
Sandy clay	ARIDISOLS	405	100	495	1.27	0.520	0.188	0.287	4.50
Sandy clay loam	ENTISOLS	240	205	555	1.31	0.505	0.121	0.406	3.75

Sorptivity measurement

The hydration velocity of the soil aggregates was measured according to the method proposed by [20]. Assuming that the shape of the soil aggregates is cubic. Six soil aggregates weighing (3) gm were taken, It was placed on the ceramic surface inside the glass funnel to increase the contact of soil aggregates with water. The sorptivity was calculated using the following method:

1. The total volume of the six soil aggregates = The mass of soil aggregates of (3) gm divided by bulk density.
2. The size of one group = The total volume of the six soil aggregates divided by (6).
3. The length of the side of the cube = The cube root (power of the 0.33) of the volume of one group.
4. Area of one face of the cube = The length of the side of the cube multiplied by itself.
5. The total surface area of soil aggregates in contact with water= The area of one face of the cube multiplied by (6).
6. The depth of the absorbed water (I) = The volume of water absorbed divided by total surface area.

The volume of absorbed water is calculated per unit time for five readings and for a period not exceeding 7-10 minutes.

While the sorptivity (S) was calculated assuming the spherical shape in the following way:

1. Six aggregates of soil are taken that passed through a sieve with a diameter of openings of (6) mm and settled on a sieve with a diameter of openings of (4) mm. After that, the mean of the diameters of the sieves (6 and 4) is found, which is equal to 5 mm and converted to centimeters, so it is 0.5 cm
2. Finding the radius of one group equal to 0.25. While the surface area of one group is calculated using the law:

$$\text{surface area} = 4 \pi r^2 \quad (11)$$

It is equal to 0.785 cm^2 surface area for one group, while the six groups are 4.712 cm^2 .

3. The surface is in contact with water for a spherical shape, assume (0.3) So the surface in contact with water is 1.413 cm^2 .
4. The depth of the absorbed water (I) is calculated by dividing the volume of the absorbed water (which is measured for each texture) by the surface in contact with the water, and by knowing the time, the sorptivity is calculated.

Results and discussion

Effective moisture content

The results showed an increase of measured effective moisture content (Se_m), at the low tension of (336) cm; It ranged from 0.488 for the clay texture to 0.354 for the sandy clay loam texture Table (3). While these values decreased with increasing tension and for all texture, the reason for this is due to the ability of fine soils to retain moisture at different tensions, which increased the values of (Se_m), the high ability of these soils to retain moisture, due to their large specific surface area and high percentages of fine interstitial spaces, which led to slow movement of water and not easy loss from the soil, and this is consistent with the results of [21]. While coarse soils lose more moisture with increasing tension, which reduces the effective moisture content values the reason for this is due to the large porous size of these soils with wide passages, which helped the movement and loss of water the moisture content is also within the porous medium of the soil, starting from the saturation state (θ_s), to the residual moisture content (θ_r), It is associated with a direct relationship with the content of soil clay; Therefore, a clear decrease was observed for the values of (Se_m), with a decrease in the proportion of clay and

all study sites. Thus, the effective moisture content is a function of the ability of soils to retain moisture and its content of clay and a means of predicting unsaturated hydraulic conductivity, and this is consistent with what was indicated by [6; 22-24]. It was also noted a secondary role for other physical soil characteristics in affecting the effective moisture content values, represented in the percentage of organic matter and porosity, which was the highest percentage in the clay texture which contributed to increasing the ability of the soil to retain water and at different tensions; While the saturated hydraulic conductivity (K_s), is a function of the soil content of clay separator and is associated with an inverse relationship with the clay percentage. The lowest value was recorded in clay soils, which was $0.075 \text{ cm} \cdot \text{hr}^{-1}$. While the highest value was at the sandy clay loam which reached $0.406 \text{ cm} \cdot \text{hr}^{-1}$. Therefore, the saturated hydraulic conductivity gives an initial idea of the values of other water functions, including the effective moisture content.

Sorptivity

The results showed that the sorptivity values calculated assuming the spherical shape of the aggregates were higher than their values for the cubic shape and for all soil textures Table (4). The reason for this is that the part in contact with the water of the soil aggregates is larger for the spherical shape, which represents 0.3 of the total area so it gives more opportunity for water absorption and movement within the porous medium; While the cube shape is the area of one face of the cube's six faces, which gives less opportunity for water movement. The geometric shape of the soil aggregates is important in understanding the movement of water and salts within the medium, and it gives an image of the regularity and distribution of particles and good construction. The geometric shape of the arrangement of the particles gives a preliminary idea of the values of the different water function. Therefore, the measured sorptivity values for the spherical shape were more realistic than the cubic shape. The results also showed that there is a direct relationship between the soil content of clay and the absorptive values, because of the role of clay with a high surface area, which gives a greater chance of moisture retention and water absorption; Then the fine silt separator of a size close to the size of clay which has a role similar to the clay, while the role of sand is reversed because of the size of its large particles. The results also showed that there is an inverse relationship between the saturated water conductivity values and the sorptivity values, we note that the clay soil, which recorded the highest values of (S), reached 410 and $0.471 \text{ (cm min}^{-0.5}\text{)}$, for the cubic and spherical shapes, respectively. It had the lowest percentage of saturated hydraulic conductivity (K_s) which was $0.075 \text{ cm} \cdot \text{h}^{-1}$; This indicates the ability of these soils to retain more water and lose it slowly, the reason for this may be due to the formation of fine bundles of capillary tubes

that have the ability to hold water in addition to the specific surface area of the clay that retain the maximum amount of water and at all tensions; as for the sandy clay loam, which recorded the lowest values of (S), which amounted to 0.330 and 0.348 ($\text{cm min}^{-0.5}$), for the cubic and spherical shapes It had the highest value of saturated hydraulic conductivity, which was (0.406) cm. h^{-1} . This reflects the ability of this soil to lose water quickly due to the weakness of the specific surface area, which increase the values of hydraulic conductivity.

Table 3.

Measured effective moisture content (Se_m) at different tensions								
Tension cm water	Moisture at tension $\theta(h)$ and Measured effective moisture content (Se_m)							
	Clay	loam	Clay loam	Silty loam	Silty clay loam	Silty clay	Sandy clay	Sandy clay loam
$\theta(h)$ 336	0.401	0.270	0.345	0.290	0.340	0.340	0.255	0.200
(Se_m)	0.488	0.456	0.470	0.433	0.472	0.437	0.373	0.354
1021	0.362	0.235	0.300	0.271	0.290	0.300	0.226	0.170
	0.397	0.345	0.353	0.370	0.333	0.329	0.281	0.258
5105	0.270	0.176	0.232	0.200	0.223	0.270	0.182	0.125
	0.183	0.156	0.169	0.133	0.147	0.140	0.136	0.112
7147	0.245	0.143	0.199	0.190	0.195	0.200	0.160	0.100
	0.125	0.051	0.080	0.10	0.069	0.059	0.072	0.032
9189	0.222	0.138	0.181	0.171	0.180	0.189	0.145	0.096
	0.072	0.035	0.032	0.036	0.027	0.029	0.025	0.019
11231	0.200	0.130	0.176	0.164	0.174	0.182	0.141	0.092
	0.020	0.009	0.018	0.013	0.011	0.010	0.0126	0.006
θ_e	0.621	0.440	0.540	0.460	0.530	0.548	0.453	0.400
θ_r	0.191	0.127	0.169	0.160	0.170	0.176	0.137	0.090

Table 4.

Sorptionity values assuming the shape of the spherical and cubic aggregates					
Texture	Clay content gm. Kg ⁻¹	(Sorptionity) as- sumption		effective moisture content at 336 cm water	Hydrau- lic conductivity, cm. hr ⁻¹
		cubic aggre- gates	spherical aggre- gates		
		(cm.min ^{-0.5})			
Clay	560	0.410	0.471	0.488	0.075
loam	210	0.349	0.364	0.456	0.255
Clay loam	350	0.438	0.459	0.470	0.144
Silty loam	200	0.400	0.421	0.433	0.200
Silty clay loam	330	0.443	0.462	0.472	0.104
Silty clay	455	0.411	0.430	0.437	0.111
Sandy clay	405	0.352	0.365	0.373	0.287
Sandy clay loam	240	0.330	0.348	0.354	0.406

Effective moisture content and its relationship to sorptivity

The results showed that the effective moisture content values, which represent one of the important and relatively easy-to-measure hydraulic functions, are a function of other hydraulic functions that are more difficult and complex to estimate. When making a relationship between the values of effective moisture content (S_e) at different tensions and linking them to the values of sorptivity (S), It was found that the best agreement appeared with us at the values of the effective moisture content at tension of 336 cm water and for all soil textures. The reason may be due to the fact that the tension of 336 cm represents the first stage of entering the water; It also corresponds to the beginning of the infiltration, so this tension was adopted as a function of sorptivity, while the effective moisture content at high tensions can be adopted as a function of other water functions such as diffusivity or unsaturated hydraulic conductivity. Therefore, the sorptivity (S) is a hydraulic property of the porous medium affected by the matric potential and has low values in coarse soils and high in clay soils. The results showed that when assuming the shape of the cubic aggregates, the relationship between the effective moisture content at tension of 336 cm water was close to the measured (S) values for all texture. Figure (1) and the fine the textures or the higher the clay content, the more accurate the values In other words, the values of effective moisture content (S_e) at this tension are close to the sorptivity (S) values with the increase in the proportion of clay ,while we have a slight difference when the percentage of clay is low and the percentage of sand is high, the reason for this may be due to the difficulty of arranging the soil granules in a cubic shape when the percentage of sand is high.

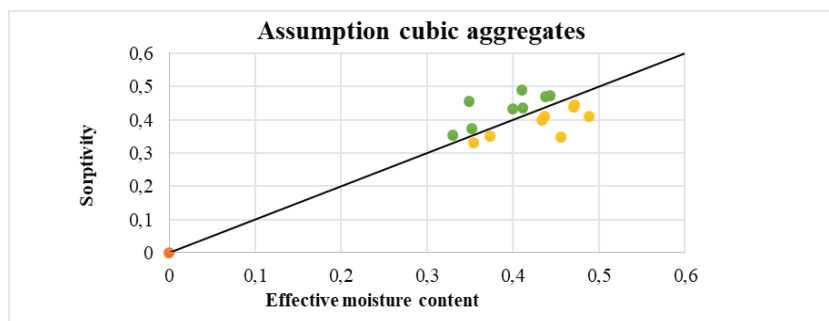


Fig. 1. The relationship between the effective moisture content and the Sorptivity values, assuming the cubic shape of the soil aggregate.

The results showed that when comparing the effective moisture content values when tension 336 cm of water with the sorptivity values, the spherical

shape of the soil aggregates has a high agreement between the values and the closeness of the values for all textures, the deviations that appeared in the cubic shape were treated when adopting the spherical shape of the soil aggregates, the reason for this may be due to the fact that the spherical shape is more realistic for the arrangement of soil grains and has a higher water absorption at effective tension and for all the texture representing different locations, Figure (2) also, adopting the area in contact with water estimated at 0.3 is more accurate to represent the surface in contact with water. Thus, the effective moisture content at tension 336 cm of water is a function or an alternative method for measuring sorptivity in an easier and suitable way for all soil textures.

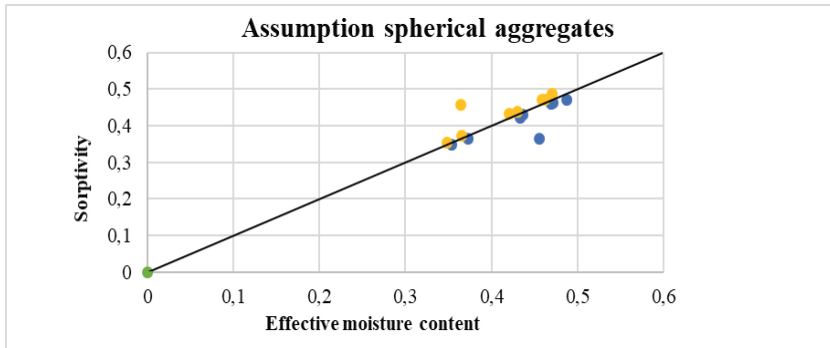


Fig. 2. The relationship between the effective moisture content and the sorptivity values, assuming the spherical shape of the soil aggregates.

Conclusion

This study proves the need to measure the effective moisture content, which is one of the important hydraulic functions, which is directly related to the physical properties of the soil especially the soil content of clay. It is one of the easy-to-measure functions. Thus, it is possible to predict difficult-to-measure hydraulic functions, depending on the effective tension. This study showed the possibility of adopting the values of the effective moisture content at tension of 336 cm of water as a function of the sorptivity values or an alternative innovative method for measuring absorbance over a large range of texture and adopting the spherical shape of the soil aggregates, is more realistic, than the cubic shape. Bearing in mind that the most suitable surface in contact with water is at 0.3 future studies can be conducted on the effective moisture content at high tensions to be a function of measuring more difficult water functions such as unsaturated water conductivity or diffusivity.

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