Assessing Two Types of Hydrogels on the Hydraulic Properties of a Sandy Loam Soil

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Abstract
Water scarcity poses a formidable challenge facing sustainable agriculture in arid and semi-arid regions. Therefore, the objective of the present study is to investigate the influence of two kinds of hydrogels (sodium polyacrylate, SAP, and polyacrylamide, CLP) on some of the hydraulic properties of a sandy loam soil utilizing the RETC program. By mixing either of the two hydrogels with the sandy loam soil using 0.0, 0.1, 0.2, and 0.3% (w/w), water holding capacity (WHS), normalized fraction of water retained (NFWR), specific amount of water retained (SWR), and saturated water increased significantly as the hydrogel rates increased. The SAP and CLP rates of 0.3% gave WHS of 0.49 and 0.46 g/g hydrogel-soil mixture, respectively. The saturated hydraulic conductivity (Ks) decreased significantly as the hydrogel rates increased. The CLP of 0.3% rate provided the lowest Ks ($5.35x10^{-5}$ m/s) that result in low water-deep percolation. The RETC program described the soil water-desorption curves well for hydrogel-soil mixture rates of 0.0 (control) and 0.3%. The residual water, available water, air capacity, and air-entry suction of the hydrogel-treated soil increased in comparison to the control. The SAP treatment provided the greatest values for the aforementioned parameters. The available water is 3.2 and 2.3-fold that of the control for SAP and CLP treatments, respectively. Both SAP and CLP treatments enhanced the specific water capacities. Getting well knowledge with the interaction among absorbents and soil may result in an efficient and economical technology for enhancing *the water management of a sandy loam soil.*

1. **Introduction**

Water scarcity promotes a wide sector of scientists to manage and conserve the water resource efficiently in arid and semiarid regions. The soils of these regions are commonly sandy/sandy loam one that is characterized by low water holding capacity. Using hydrogel could be a promising technology for conserving in these soils especially. Better knowledge of the interaction between hydrogels and sandy soil may lead to better water use. Zekry *et al.* [1] recovered superabsorbent polymer (SAP) from disposable diapers. They used the SAP in view of environment and water conservation. The SAPs concentration at 1.6% increased the sandy retained water by 2.6 folds compared to control soil [1]. A maximum swelling capacity of 189 g-g $^{-1}$ of dry gel was obtained [1]. Repeating wetting and drying process for six months reduced the ability of recovered SAP-sand mixture to retain water by 14% in comparison to the initial wetting cycle .[1]. Liao *et al*. [2] reported similar results for the retained water under suction between 0.0 and 30 m. The synthetic and bio-

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based hydrogels enhanced water retention in soil comparison to control [3]. Additionally, both hydrogels decreased saturated hydraulic conductivity, reduced infiltration, and decreased soil evaporation. Similarly, Al-Omran *et al.* [4] and Takahashi *et al*. [5] found increases in the soil availably water of sandy soils. Al-Omran and Al-Harbi [4] reported a reduction in the hydraulic conductivity by mixing polymer with sandy soil. Bhardwaj *et al*. [6] reported that water retained by the absorbents (cross-linked polyacrylamides (PAM)) (at low suction) ranged between 200 and 500 kg kg^{-1} of polymer; water retained by the polymers when mixed with sand ranged between 40 and 140 kg kg^{-1}. Tian *et al*. [7] reported 97.7% increase in the retained water after 16 h at 25 ℃ by hydrogel and inhibited water evaporation. Abedi-Koupai *et al*. [8] used two hydrogels, (PR3005A and Tarawat A100) in four levels (2, 4, 6, and 8 g kg^{-1}) mixed with three soil textures (sandy loam, loamy and clay). The results showed that for each texture, hydrogels caused the residual water and saturated water content increase. Application rate of 8 g kg^{-1} increased the available water content 1.8-fold in clay and 2.2 to 3.2-fold in loamy and sandy in comparison to control. Also, they reported that air -entry suction increased in sandy loam soil and decreased in the other soils. Nada and Blumenstein [9] evaluated the impact of hydrogel Nanocomposite (PSHNC) on the soil water retention of sandy soil at levels (0.0, 0.1, 0.2, 0.3 and 0.4% w/w). Their results revealed that, the soil amended with 0.1-0.4% (w/w) of PSHNC enhanced the moisture retention at field capacity, wilting point and the plant available water. Albalasmeh *et al*. [10]'s results revealed that, 0.33% hydrogel (cross-linked potassium poly-acrylic acid with size of 0.2–0.8 mm in diameter) concentration increased the soil available water by 49% and prolonged time for water evaporation. Evaluation of SAP on the hydraulic properties of sandy soil has a great attention. The hydraulic properties are crucial in several areas of soil, water, nutrient, and salinity transfer, and energy fate [11]. The soil-water desorption curve describes the relationship between the volume fraction of water θ and the matric potential h and is strongly affected by soil texture or hydrogel types. Reynolds *et al*. [12] reported that soil porosity and water release characteristics directly influence a range of soil indices including soil aeration capacity, plant available water capacity, and relative field capacity. However, assessing of the SAP and polyacrylamide (CLP) using desorption -water curve which is one of the important hydraulic properties of soil is limited. Therefore, the objective of this study is to investigate the effects of two hydrogels (SAP and CLP) mixed at various rates with a sandy loam soil on some soil water hydraulic properties and soil water desorption curve described by the RETC computer program.

2. Materials and Methods

2.1. Hydrogel

Two hydrogels were utilized: commercial hydrogel cross-linked polyacrylamide (CLP) and cross-linked sodium polyacrylate (SAP). The particle size of CLP was 1000–2000 μm in diameter with chemical stricture of $R\text{-}CONH_2$ [13], and SAP size particle was 90-850 μm with chemical formula of $[\text{-}CH_2\text{-}CH\ (COONa)\text{-}]n$ [14]. Saturating cation was Na^+ for SAP. Either of the hydrogels was mixed with the dry sandy loam soil to different mixture ratios depends on the type of experiment.

2.2. Experimental soil

The experiments were conducted using a sandy loam soil from Etehad area, Kom Hamada province, Beheira Governorate, Egypt (≈ latitude of 31° 02' 23.8"N and 30° 26' 23.6"E). The soil was previously classified as Typic Quartzipsamments [15]. The climate of governorate is typically Mediterranean with dry and hot summers and cool and wet winters. The yearly mean temperature is 20.4° C. Annual rainfall is 102 mm, mainly falling in the months of November through February [16]. The soil was collected at a depth of 0–30 cm, air-dried and sieved through a 2-mm sieve prior to usage. The soil contained 80, 7, and 13% of sand, silt, and clay, respectively. Two laboratory experiments were conducted to evaluate the impact of two kinds of hydrogel on the water absorbency of hydrogels and soil– hydrogel mixtures (first one), and water desorption curve (second one) of the hydrogel-soil mixtures.

2.3. Water absorbency of SAP and CLP hydrogels, and Soil– hydrogel mixtures

Several measurements were determined in triplicates. The measurements were achieved for either hydrogel only or in hydrogel-soil mixture using 0.0, 0.1, 0.2 and 0.3% w/w hydrogel rates. These rates were chosen because numerous scientists used them in arid and semi-arid sandy area [3, 8, and 17].

2.3.1. The water absorbency capacity (WAC)

To describe the kinetic swelling behavior of SAP and CLP, some measurements were conducted as described by Zekry *et al*. [1]. The hydrogel weight (1g) was immersed in a tap water (0.2 dS m^{-1}) to observe the swelling equilibrium at room temperature using tea bag through 60 minutes. During the first 6 after immersing, the bags were removed each minute then were removed each 5 minutes in the rest of immersing period. The WAC at such a time was calculated using the following equation:

$$\mathrm{WAC} = \frac{\mathrm{W_2 - W_1}}{\mathrm{W_1}} \qquad (1)$$

Where WAC is amount of water per amount hydrogel (g water/ g hydrogel), W1 is the weight of dry hydrogel and W2 is the weight of equilibrated swollen hydrogel at a specific time.

The WAC was described as a function of time using the following equation:

$$\mathrm{WAC(t)} = \mathrm{a}\big(1 - \exp(-\mathrm{bt})\big) + \mathrm{c}\big(1 - \exp(-\mathrm{dt})\big) \qquad (2)$$

Where WAC (t) is the polynomial value at t (absorbing time) and a, b, c, and d are polynomial coefficients. Equations (2) were fitted to the average values WAC to estimate the polynomial coefficients. The first derivative of WAC is the rate of water absorption (g water/min).

2.3.2. Water holding capacity (WHC)

For assessing effects of hydrogel on soil water properties, a sandy loam soil was mixed with either type of the hydrogel (SAP or CLP) aforementioned rates. The water holding capacity was determined in hydrogel-soil mixture as described by Zekry *et al*. [1] as following:

$$\mathrm{WHC} = \frac{\mathrm{W_w - W_d}}{\mathrm{W_d}} \qquad (3)$$

Where WHC is the water holding capacity (-), Ww is final wetted hydrogel-soil mixture (g), and Wd is dry weight of mixture (g).

2.3.3. Normalized fraction of water retained (NFWR)

The NFWR was calculated as described by Zekry *et al*. [1].

$$\mathrm{NFWR} = \frac{\mathrm{W_{Am} - W_d}}{\mathrm{W_{As}}} \qquad (4)$$

Where NFWR is normalized fraction of retained water (-), WAm is the average water absorbed by the hydrogel-soil mixture (g); and W_{As} is the average water absorbed by the untreated soil (g).

2.3.4. Specific amount of water retained (SWR)

The specific amount of water retained (SWR) is the amount of absorbed water by a unit weight of hydrogel in the soil–hydrogel mixture at a given level of hydrogel [18] and [1]:

$$\mathrm{SWR} = \frac{\mathrm{(A - B)}}{\mathrm{C}} \qquad (5)$$

Where SWR is specific amount of retained water (-), A is the wet weight of the soil–hydrogel mixture (g), B is the wet weight of soil only (g) and C is the dry weight of soil–hydrogel mixture (g).

2.3.5. Saturated hydraulic conductivity (Ks)

The soil –hydrogel mixtures of soil samples were packed in PVC column bulk density of 1.7 Mg/m. The packed columns were water saturated by capillarity overnight. Saturated hydraulic conductivity (Ks) was calculated according to the Eq. 6 by using the constant head method as described by Klute and Direksen [19]:

$$K_s = \frac{Ql}{hat} \qquad (6)$$

where, Ks (m/s) is the saturated hydraulic conductivity, Q (m^3) is the volume of the percolating water, l (m) is the height of the soil–hydrogel mixture column inside the core, h (m) is the total head, a (m^2) is the cross sectional area of the soil column sample and t (s) is the time of collecting percolates.

3.4. Measurements of water-desorption properties of soil

The soil water-desorption curves, one of the hydraulic properties, were determined in the laboratory using a pressure plat apparatus as described by Lu *et al*, [20].The hydrogels (SAP or CLP) were mixed with the sandy loam soil at 0.3% w/w and a bulk density of 1.7 Mg m^{-3} then placed in the pressure plate in retaining rings. The hydrogel-soil mixtures were saturated with a tap water (EC = 0.2 dS/m) overnight beside a sandy loam soil sample as a control. The pressures of eleven values (0, 1, 3, 5, 8,10,20,30, 40, 50, and 100 m) were used. These pressures were applied until equilibrium and the soil/hydrogel-soil mixture water were considered to be in equilibrium with the applied pressure. The gravimetric water content for each treatment was determined by oven drying at 105 ^{0}C. The soil volumetric water content was then determined by multiplying the gravimetric water content by the ratio of the soil bulk density to water density. The computer program, RETC [21].was used for obtaining optimal model parameters for nonlinear equations (Eq. 7) (Table 1). The RETC program used the parametric models of van Genuchten (Eq. 7) to represent the soil water-desorption curve. The soil water -desorption curves can be characterized by the van Genuchten model [22]:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha h)^n]^m} \qquad (7)$$

Where:
θ (h) is the water retention curve [m^3/m^3];
h is is suction head (m) of water;
θs is saturated water content (m^3/m^3);
θr is residual water content (m^3/m^3);
α is related to the inverse of the air -entry suction, α (1/ m); and,
n is a measure of the pore-size distribution, n>1 (dimensionless) and
m=1-1/n

Water content can be expressed in relative water, Θ, or effective saturation as:

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (8)$$

The differential water capacity, C (θ) (1/m), was developed to describe the change rate of soil water content as function of water suction [22].

$$C(\theta) = \frac{d\theta}{dh} = \frac{-m(\theta_s - \theta_r)}{h(1-m)} \Theta \left(1 - \Theta^{\frac{1}{m}}\right) \qquad \textbf{(9)}$$

The differential water capacity was calculated in the present work using the equation above as a predicted value.

The differential water capacity C(θ) can be obtained from the soil water-desorption curves by graphic differentiation [23] (i.e., by measuring the slope of wetness versus suction head curves at different values of suction). Therefore, C was obtained as the slope of the measured desorption curve to give a measured value in the present work as following:

$$C(\theta) = \frac{\Delta\theta}{\Delta h} \qquad (10)$$

Some moisture parameters were acquired from desorption curve such as air-entry suction (ha), air-capacity, and air content.

$$Air\ content = \theta_s - \theta(h) \qquad (11)$$

Where air content is volumetric air content at suction h and θ(h) is the volumetric water content at suction h.

$$Air - Capacity = \theta_s - \theta_{air} \qquad (12)$$

Where Air-Capacity is volumetric pore (m^3/m^3), θair is the volumetric water content (m^3/m^3) at a suction head of 1 m [24], on the soil water desorption curve.

Table 1: The estimated parameters using the RETC of Eq. 7 for the studied treatments.

Treatment	θ_s (m^3/m^3)*	θ_r (m^3/m^3)	α (m^{-1})	n (-)
control	o.35	0.043	15.2	1.584
0.3 % CLP	0.44	0.158	11.8	1.305
0.3 % SAP	0.60	0.221	1.8	1.758

*Measured values

3. Results and discussion

3.1. Water Absorbency of SAP and Soil–hydrogel Mixtures

The water absorption capacity (WAC) was depicted in Figure 1 for the two soil –hydrogel mixtures (SAP and CLP). The WAC function explores the swelling degree of hydrogels. WAC increased fast in the first ten minutes then showed small steady increase with further time. The SAP showed high WAC in comparison to CLP. The measured WAC was described using Equation 2 well with R^2 values of 0.997 and 0.998 for SAP and CLP, respectively. Therefore, the first derivative of the equation can estimate a reliable water absorption capacity rate that shown in Figure 2. Both WAC and its rate showed two stages but in opposite trends. The first stage extended for ten minutes and second stage extended with further time in both curves. The first stage showed increases abruptly with WAC (Figure 1) and decreases its rate (Figure 2). The second stage showed slow change with time. Both SAP and CLP showed very similar values for the absorbance rate during the second stage (Figure2). It is suggested that first swelling stage of SAP and CLP depends on the matric potential gradient that was high initially. The water potential in water outside the hydrogel chain is high while water potential inside the hydrogel is very low. The results of Zekry *et al.* [1] showed similar results for the recovered SAP from the disposable diapers. However, they represented the two stages separately (the first stage stands for 6 minutes while the second covers a period from five to 60 minutes). [25]'s results explored the degree of swelling of pure polyacrylamide in water that was low compared to that of alkali-hydrolysed sample. In both cases degree of swelling increases with time and then becomes constant. They ascribed the great of swelling of polyacrylamide to its hydrophilic nature and the capability of hydrogen bonding of acrylamide with water. The molecular size and degree of crosslinking greatly influence the water absorbency of gels. Similar findings by Queirós *et al.* [26] for the swelling kinetics of Pam-Ac and Pam-Ac/ES in water. In all cases, the swelling rate is greater during the first few minutes and then reaches an equilibrium plateau. In the case of water, the degree of swelling for Pam-Ac/ES was around twice that for Pam-Ac (629 ± 28 g water g^{-1} dry hydrogel for the latter).

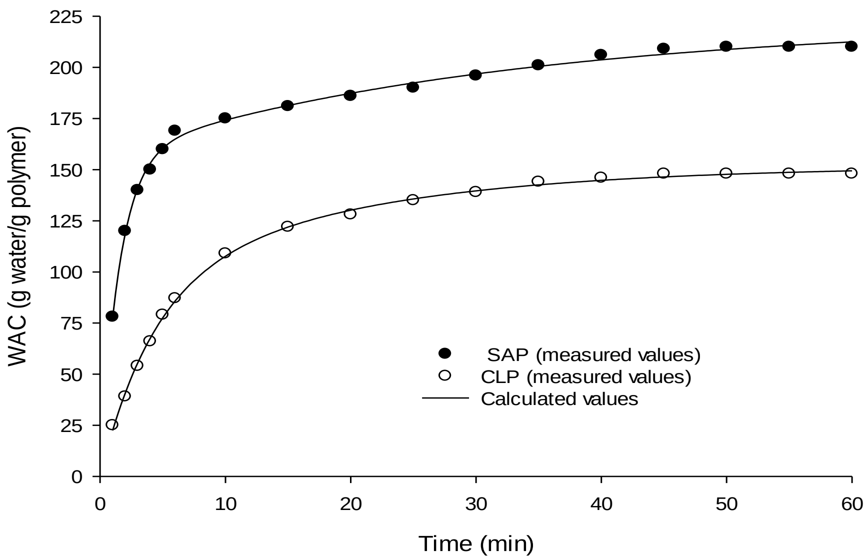


Fig 1: water absorption capacity (WAC) of hydrogels as a function of time measured (symbol) and calculated (solid line)

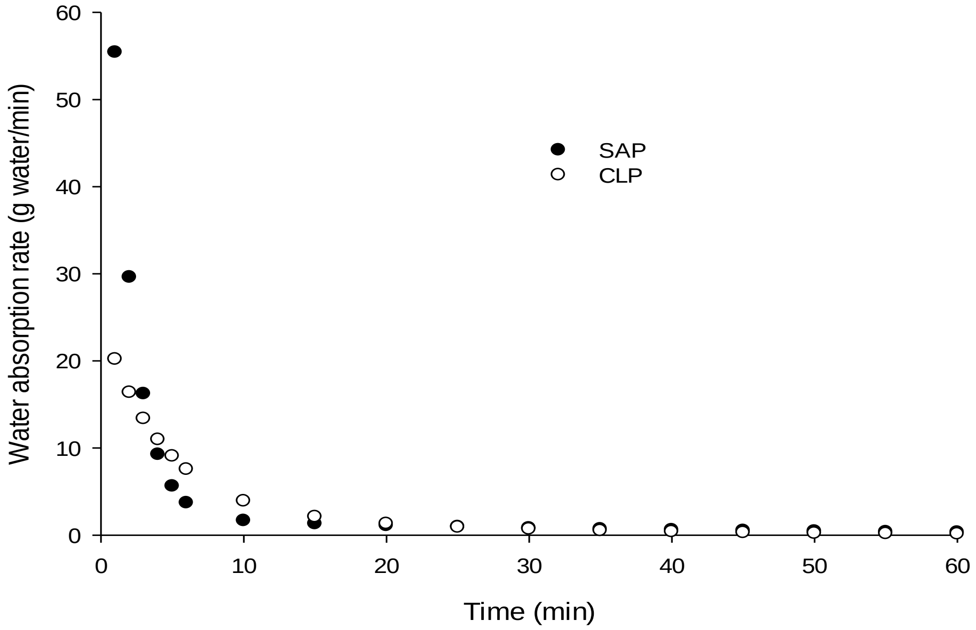


Fig .2: Water absorption rates as a function of time for two hydrogels

The water holding capacity (WHC) of hydrogel-soil mixture for four rates of either SAP or CLP is presented in Table 2. Generally, the WHC increased as the rates increased significantly. The ratio of WAC of the hydrogel-soil mixture to 0.0 % level (control) was 1.23, 1.42 and 1.58 for 0.1, 0.2, and 0.3 % SAP rates, respectively. The corresponding ratios for the CLP were 1.16, 1.35 and 1.48. The whole average of WHC for the three rates was 0.44 and 0.41 for the SAP and CLP, respectively. It is obvious using the SAP for improving the WHC was superior to the CLP. Many studies showed similar trends for using hydrogel. For example, addition of 0.1, 0.2 and 0.3% hydrogel increased the moisture retention (θ_r) at field capacity linearly (R^2 = 0.988) and thus the amount of plant available water significantly in both sandy loam and loam soils compared to the untreated soils [27]. Čechmánková *et al.* [28]'s their results showed an unequivocally positive effect of whey-based hydrogel on water retention, basic soil properties and nutrients concentration with different levels of hydrogel.

Table 2: The water holding capacity (WHC), net fraction retained water (NFRW) specific water retained (SWR) and saturated hydraulic conductivity (K_s) for soil / both hydrogel-soil mixtures (SAP and CLP) with statistical analysis ($LSD_{0.05}$).

Treatment	WHC (g/g)	NFRW(g/g)	SWR(g/g)	K_s (m/s)x10^{-5}
SAP 0.3	0.49 a	0.37 a	0.18 a	1.0 e
CLP 0.3	0.46 b	0.35 b	0.15 b	0.5 g
SAP 0.2	0.44 c	0.34 c	0.13 c	1.3 c
CLP 0.2	0.42 d	0.32 d	0.11 d	0.7 f
SAP 0.1	0.38 e	0.29 e	0.07 e	1.5 b
CLP 0.1	0.36 f	0.28 f	0.05 f	1.0 d
Control	0.31 g	0.24 g	----	1.9 a

The normalized fraction of water retained (NFWR) values as a function of hydrogel rates were showed in Table 2. The values of NFWR for the SAP were 0.29, 0.34 and 0.37 for the 0.1, 0.2 and 0.3% SAP rates, respectively. The corresponding CLP rates gave 0.28, 0.32 and 0.35. The zero level (Control) had NFWR of 0.24. The differences among the treatments were significant. Obviously, the Hydrogel rates increased positively the NFWR. The third measurements for evaluation the performance of SAP and CLP hydrogels involved in the Specific amount of water retained (SWR) (Table 2). Both NFWR and SWR data support the presented WHC. We conclude that using either hydrogel of SAP or CLP is a promising solution tools for water conservation. Khan et al. [29] ascribed ability of hydrogel for absorbing water to the density of the cross-linking point, the concentration, and the spatial distribution of the hydrophilic groups within the matrix. When the dried hydrogels are hydrated in soil, the swelling equilibrium occurs in nearly 600 min, while in aqueous media in 60 min at all CS/CA weight ratios tested.

Table 2 presented the saturated hydraulic conductivity (K_s) for the treated soil with SAP and CLP in comparison to control treatment. The K_s values followed the order of control > SAP > CLP treatments. Commonly the K_s decreased as hydrogel increased. The K_s values differed significantly among the treatments. The K_s of the control was 1.92-fold that of SAP treatment and 3.57-fold of the CLP treatments at 0.3% SAP or CLP rate. In comparison to saturated hydraulic conductivity of the control, the 0.3% SAP decreased *Ks* by 48% while the CLP % decreased *Ks* by 72%. The great reduction of K_s for the CLP–soil mixture might be ascribed to the large size of its particles (avg. 1500 µm) of CLP in comparison to the SAP size particle (avg. 470 µm) in SAP-soil mixture. The large particle size of CLP can block the big pores that are effective in water transport in saturated soil. Similar results for Ks for amended soil by hydrogel were reported in numerous studies. For example, the K_s of was statistically significantly decreased with the application of hydrogel (Alkali Lignin-Based Hydrogel) at 0.1 and 0.3% (w/w) compared to the control treatment [3]. The implication of this study is that SAP or CLP could swell and retain water in saturated soils and the bound water could be released to enhance the flow of soil water in unsaturated soil, thereby reducing the water stress of plants, which require less energy to move and absorb water. The lower hydraulic conductivity would reduce deep percolation of water in the soil while increasing soil water storage. Concerning the availability of plant nutrients and reducing the pollution of water resources, the low saturated conductivity in SAP or CLP treated soils could enhance both issues.

3.2. Water-desorption properties of soil

Figure 3 presented soil water- desorption (drying) characteristics of hydrogel-soil mixtures (0.0 and 0.3% SAP or CLP) between 0 and 100 m of water potential head. The Figure showed the measured and predicted retention curves. The RETC Model program was used for the prediction. The program produced the soil water content with great efficiency because R2 was more than 0.98 for the treatment explored. The SAP soil mixture showed more water content than either the CLP mixture or the control treatment at any suction head. The soil water content at 0.0 m water potential (saturated water content) was 0.6, 0.44 and 0.35 on volume bases, for the SAP, CLP and control treatments, respectively. Therefore, it is incepted that the treated SAP mixture can provide water with slow release rate to such a plant for a long time in comparison to either the CLP or control treatments. The desorption-curve showed three change stages. The first stage showed high decrease in water contents in the range of 0 to 0.75 m water potential head.

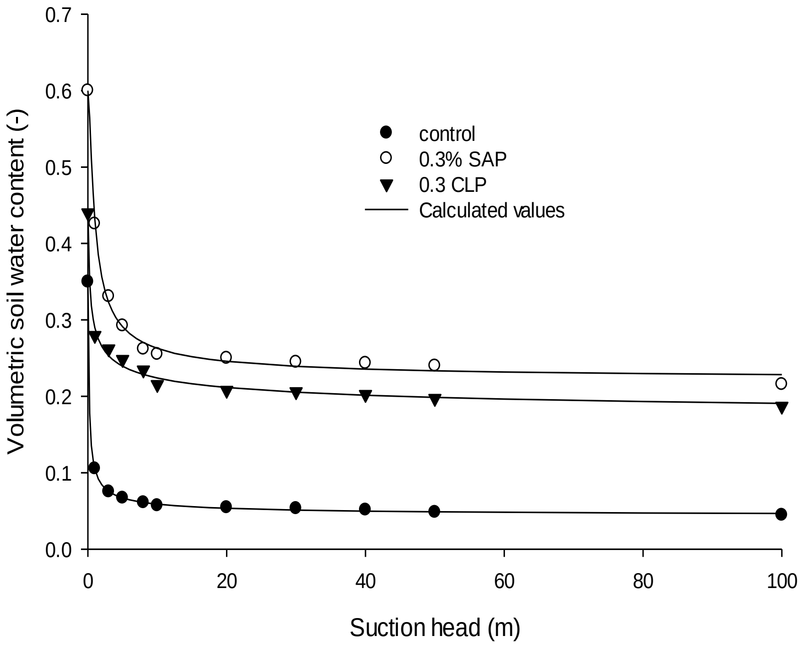
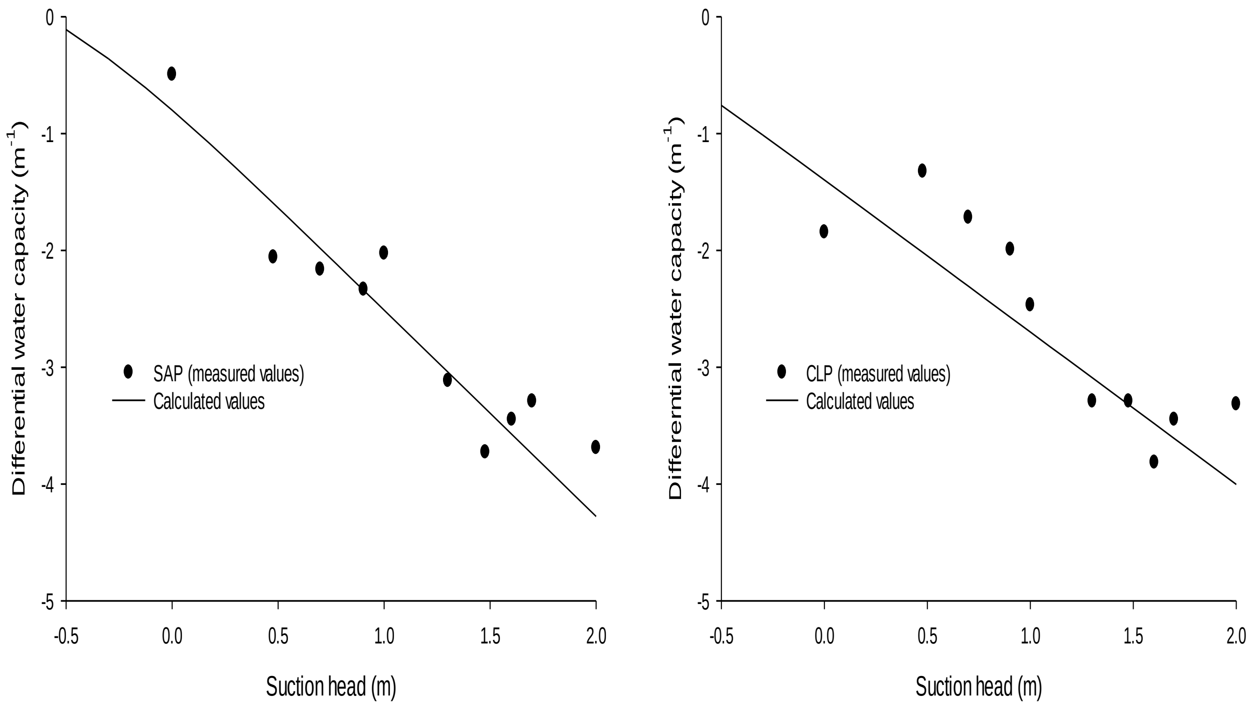


Fig.3: water – desorption curves of hydrogel-soil mixtures as affected by hydrogel type, measured (symbol) and calculated (solid line)

The second stage showed low changes in soil water contents that extended in the potential heads range 0.75 to 20 m. The last stage showed very slow change in soil water content with suction head and was confined in potential head range of 20 to 100 m. similar findings, the results showed that the SAP increased the water retaining capacity of soil as suction head range between 0 and 30 m compared to control [2]. Contrarily, SAPs barely increased the amount of plant-available water of sandy soil in a potential range of -0.392 to −9.810 m, but significantly increased the soil water at <−9.8 m [5].

3.3. Differential water capacity (C)

The C was predicted using RETC model [30].The function of C is to describe the release of water, as the soil gets dry. The C was predicted using RETC model [21]. and Eq 9. Additionally, the differential water capacity ($\frac{\Delta\theta}{\Delta h}$) can be measured from the soil moisture characteristic curves by graphic differentiation using Eq. 10 [23].The function of C is to describe the release of water as the soil gets dry. The measured and predicted values of C were presented in Fig. (4) As a function of water suction head in log-log scale. Generally, the values of C were reduced as the suction head increased for treatments. Visibly, the measured and predicted water capacities are in a good harmony. The calculated values of C (1/m) at suction of 1 m are $364.0x10^{-4}$, $401.0x10^{-4}$ and $1587x10^{-4}$ for the control, CLP, and SAP. Respectively. The corresponding values of C (1/m) at suction of 10 m were $9.5x10^{-4}$, $20.0x10^{-4}$ and $30.9x10^{-4}$. It is concluded that the releasing water rate was high for SAP and CLP in comparison to the control and decreased with further increases in the soil water suction.



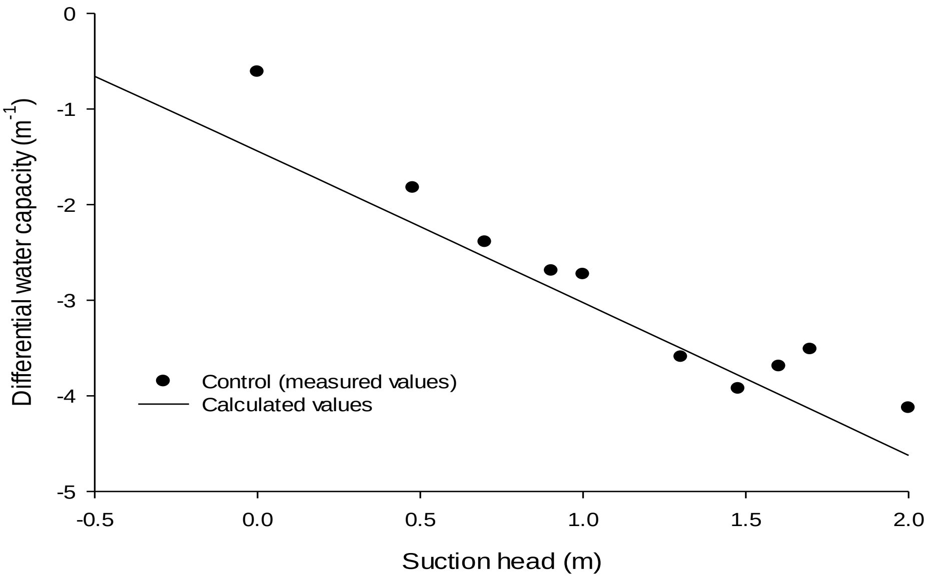


Fig .4 : differential water capacity as a function of suction head for different hydrogel – soil mixture types

The presented-desorption curve previously was used to calculate the air content as a function of suction (Eq. 11). The amount of air contained by the soil alone and the hydrogel-soil mixtures as a function of suction are presented in Figure 5. The predicted and measured air content are on harmony and consistent together. The curves of air content showed inversely change to the soil water-desorption curves. As the suction increased, the air contents increased. The increasing air content is due to losses soil water that replaced by air. Interestingly, the air content percentage followed the order: SAP > control > CLP treatments. These results were correlated to the data of water desorption curve because a high air content corresponds to high water lost.

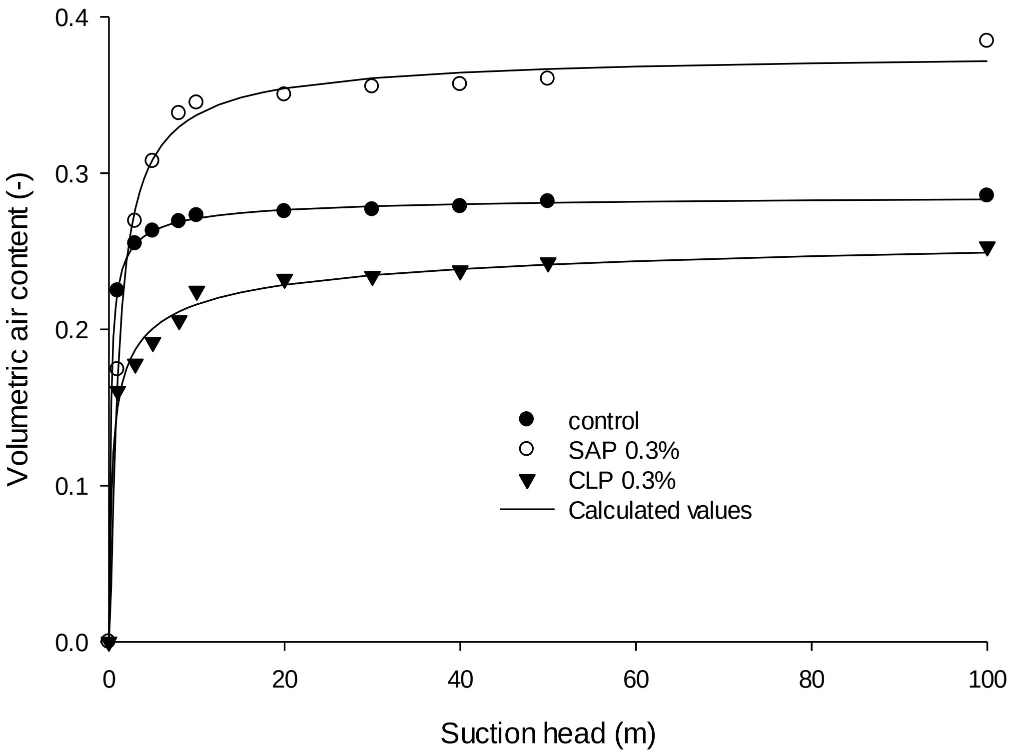


Fig. 5: Volumetric air content for hydrogel-soil mixture as affected by hydrogel type and suction head.

3.4. Saturated Water Content (θ_s)
The hydrogel application increased volumetric of the saturated water content (θ_s) (measured ones) in compassion to untreated hydrogel soils (control) (Figure 6). The presented θ_s is a measured value. The increase in θ_s depends on the hydrogel type. The θ_s of the SAP-soil mixture is much greater than its value for CLP-soil mixture. The results indicate that θ_s of the SAP and CLP treatments were 1.7 and 1.3-fold, respectively, that of control.

3.5. Residual Water Content (θr)
The variation of (θ_r) in each soil hydrogel -mixture in Figure 6. θ_r values were obtained as a fitting constant using the RETC model. The value of θ_r was affected by hydrogel application and its type similarly to the saturated water contents, θ_s . However, θ_r of the SAP and CLP treatments were 5.2 and 3.7 times, respectively, that of the control. It is clear the θ_r hydrogel treatment ratio to the control is great in comparison to the ratio of $\theta_{s.}$

3.6. Field Capacity (FC).
The variations of (FC) calculated using the RETC program in soil hydrogel -mixture were shown in Figure 6. The value of FC is enhanced similarly by hydrogel application and its type to the saturated water contents. The FCs of the SAP and CLP treatments was 4.3 and 3.4 times, respectively, that of the control. It is clear the soil water content FC hydrogel treatment ratio to the control is great in comparison to the ratio of $\theta_{s.}$ Shahid et al. [31].results of soil amendment with 0.1, 0.2, 0.3 and 0.4 w/w % of superabsorbent hydrogel nanocomposites (SHNCs) enhanced the moisture retention significantly at field capacity compared to the untreated soil.

3.7. Wilting point (WP)
The WP is figured out from the RETC program data. The variation of (WP) in each soil hydrogel-mixture was presented in Figure 6. Application either hydrogel increased WP similarly to the previous moisture constants. However, WP of the SAP and CLP treatments were 4.9 and 4.1 folds, respectively, that of the control. It is worth noticed that the ration of the above constants to the control increased as the hydrogel-soil mixture got dried.

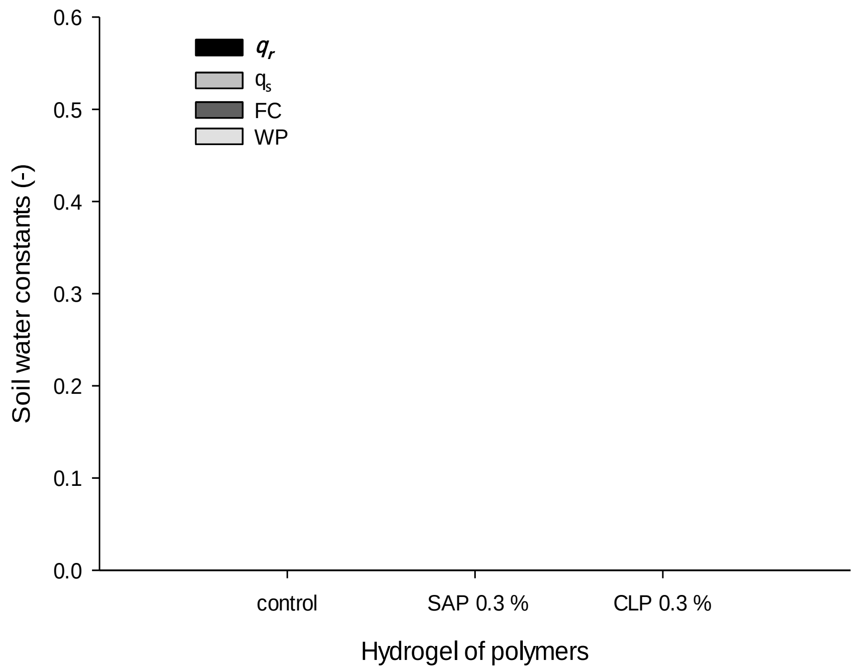


Fig. 6:Residual water (θr), saturated water (θs), field capacity (FC) and wilting point (WP) constants as affected by hydrogel-soil mixture types.

3.8. Available Water (AW)

The values of volumetric water content at field capacity (FC) and permanent wilting point (PWP) presented earlier were used to determine the available water (AW) that shown in Figure 7. The AW is 3.2 and 2.3-fold that of the control for SAP and CLP treatments, respectively. Interval of irrigation can be prolonged as AW increased. Increasing such an irrigation interval results for agricultural water conservation. Similarly, hydrogel should enhance plant growth, especially if water is limiting, because of the increase in the AW [32; 31]. Albalasmeh *et al*. [32].stated the lowest AW is 15.7% for the control and the highest AW is 23.4% for the 0.33% concentration of hydrogel. Using SAP at 0.4 % w/w, Agaba et al. [33] reported an increase in the plant available water by a factor of about three in sand, two-fold in silt loam and one-fold in sandy loam, loam and clay soils compared to the control. Swollen SAPs principally hold water in the range of −9.8 to −39.2 cm in sandy soil, suggesting that SAP induces a transition from gravitational water to readily plant-available water by swelling itself [5].While, the former authors showed that SAPs barely increased the amount of plant-available water in a potential range of 39.2 to −981.0 cm, but significantly increased the soil water at <−981.0 cm.

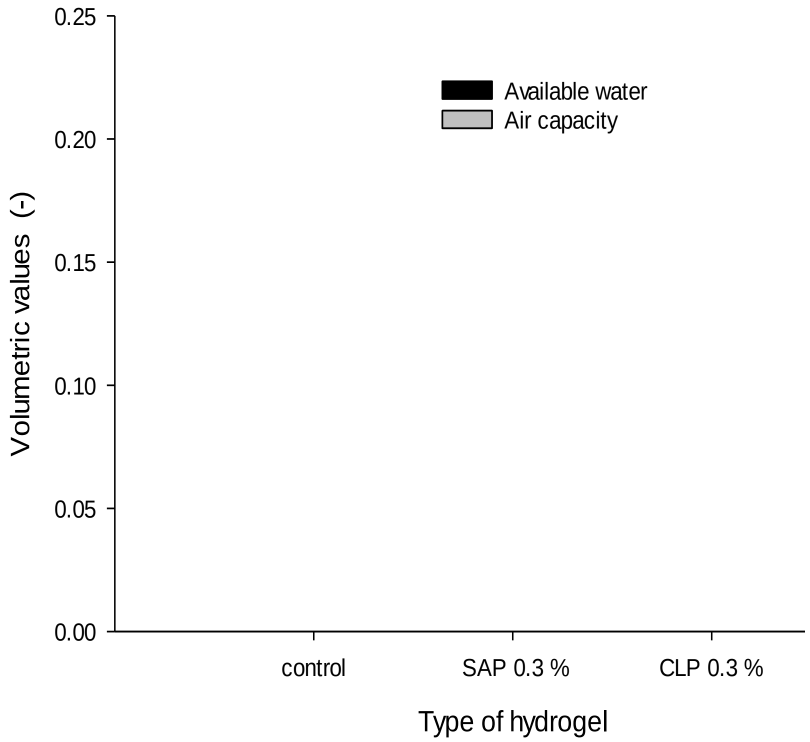


Fig. 7: Available Water and Air-Capacity (-) as affected by hydrogel-soil mixtures type.

3.9. Air-Capacity

The Air-Capacity was determined using (Eq.12). Air-Capacity (AC) is the proportion of soil volume drained pores between pressure potentials of 0 and –10 kPa. At this point pores >30 µm are drained [24].It is obviously addition of both hydrogels (SAP & CLP) to the sandy loam soil reduced the air-capacity considerably comparison to the control (Figure 7). The Air-Capacity values were 0.2448, 0.1743, and 0.1605 for the control, SAP and CLP treatments, respectively.

$$\textbf{Air- Entry suction } (h_a = 1/\alpha) \qquad \textbf{(Eq.12).}$$

The water-desorption curve changes abruptly with air- entry value. Due to larger pore geometry in sandy loam soils, water is released under lower matric suction that provides a high value of α. The value of α in control, CLP, and SAP treatments are 15.2, 11.8, and 1.8 m (Table 1), respectively. Adding hydrogel of CLP or SAP in sandy loam soil reduced the largest pores in the soils into small ones and the pressure required for water releasing is increased. Consequently, the value of α is reduced. As stated earlier, the Air-Entry suctions are equal to the inverse of α. Therefore, the air-entry suctions are 0.066, 0.085 and 0.544 m for the control, CPL and SAR treatments, respectively. Hydrogel addition to these soils may open the media, by forcing soil particles apart, increasing aeration. Hence less pressure is needed to desorb water and the value of α is increased.

4. Conclusions

This study provides an approach to the use of hydrogels in agriculture. Our results indicate that hydrogels are a prospective option for sustainable agriculture and fulfill environmental and production benefits. Polyacrylamide (CLP) and sodium polyacrylate (SAP) give flexible utilization potential keeping the primary effect of hydrogel to hydraulic properties of the sandy loam soils. The properties such as soil water available, water holding capacity of hydrogel (WHC), net fraction retained water (NFRW), specific water retained (SWR), the residual soil water (θs) and air-entry suction increased by the application of either hydrogel in comparison to the control. Contrary, the air-capacity and saturated hydraulic conductivity decreased by the application of either hydrogels. The reduction in the former properties were higher for CLP in comparison the treated SAP soil. The increases of former or decreases in the later properties lead to improving the ability of soil for water conservation. Our results showed that using either SAP or CLP is a promising solution toward conserve water, fertilizer and environmental contamination.

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تقييم نوعين من الهيدروجيل على الخصائص الهيدروليكية للتربة الطميية الرملية

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تشكل ندرة المياه تحديا هائلا يواجه الزراعة المستدامة في المناطق القاحلة وشبه القاحلة. تغطي التربة الرملية ذات الترشيح العالي للمياه والقدرة المنخفضة على الاحتفاظ بالمياه مساحة كبيرة في هذه المناطق. تلعب الخصائص الهيدروليكية لهذه التربة دورا حاسما في تحديد جودة التربة والبيئة وقدرتها على خدمة النظام البيئي. ولذلك ، فإن الهدف من هذه الدراسة هو التحقيق في تأثير نوعين من الهيدروجيل (بولي أكريلات الصوديوم SAP و بولي أكريلاميد CLP) على بعض الخصائص الهيدروليكية للتربة الطميية الرملية باستخدام برنامج RETC. عن طريق خلط أي من الهيدروجيل مع التربة الطميية الرملية باستخدام (٠,٠ و ٠,١ و ٠,٢ و ٠,٣ ٪ (وزن/وزن)) ، والقدرة على الاحتفاظ بالمياه (WHS) ، و NFWR ، و SWR ، والسعة التشبعية للتربة زادت بشكل كبير مع زيادة معدلات الهيدروجيل. أعطت معدلات SAP و CLP ٠,٣ ٪ WHS من ٠,٤٩ و ٠,٤٦ جرام/جرام هيدروجيل- خليط التربة ، على التوالي. انخفض معامل التوصيل الهيدروليكي المشبع (Ks) بشكل ملحوظ مع زيادة معدلات هيدروجيل. معاملة CLP بمعدل ٠,٣ ٪ حقق اقل معدل Ks (٥,٣٥ x ١٠ -٥ م/ث) مما يؤدي إلى انخفاض الترشيح العميق للمياه. وصف برنامج RETC منحنيات امتصاص المياه للتربة بشكل جيد لمعدلات خليط هيدروجيل التربة من(٠,٠-معاملة الكنترول) و ٠,٣٪. زادت المياه المتبقية والمياه المتاحة والسعة الهواء وضغط دخول الهواء للتربة المعالجة بالهيدروجيل مقارنة بمعاملة صفر جلز اعطت معاملة SAP أكبر القيمللصفات المذكورة أعلاه. المياه المتاحة هي ٣,٢ و ٢,٣ أضعاف بمعاملة صفر جل في معاملات SAP و CLP ، على التوالي. عززت كل من معاملات SAP CLPالسعة المائيةالنوعية. قد يؤدي التعرف الجيد على العلاقة بين المواد المدمصة للماء والتربة إلى تقنية فعالة واقتصادية لتعزيز إدارة المياه في التربة الطميية الرملية.