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Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices

Jahangir Abedi Koupai[1], Seyed Saeid Eslamian[2], Jafar Asad Kazemi[2],

[1]Water Engineering Department, College of Agriculture,
Isfahan University of Technology, Post Code 84156, Isfahan, Iran.
e-mail: koupai@cc.iut.ac.ir
[2]Water Engineering Department, College of Agriculture,
Isfahan University of Technology, Post Code 84156, Isfahan, Iran.

Abstract

The effects of hydrogels on the soil water retention characteristic curve (WRC) and on the growth indices of *Ligusrum ovalifolium* (an ornamental plant dominating in the landscape of central Iran) were studied. Various amounts of hydrogels (Suprab A200) were added to soil samples having different percentage of water proportional to potential evapotranspiration data. A factorial experiment was used for statistical analysis of data. The results of the soil water retention model showed that, hydrogel caused the residual water content and saturated water content to increase. Available water content increases to a maximum of about 2.3 times the control. Application of hydrogels can result in significant reduction in the required irrigation frequency particularly for coarse-textured soils. This is an important issue in arid and semi-arid regions of the world for enhancing the water management of coarse-textured soils.

Key words: Soil water retention, *Ligusrum ovalifolium*, super absorb, arid zones, water scarcity.

1. Introduction

Ecohydrology is a new concept which suggests that the sustainable development of water resources depends on the ability to maintain the ecosystem processes that have been established by evolution. These ecosystem processes regulate water and nutrient circulation and energy flow at the basin scale in two ways: biota is regulated by floodplain hydrology and hydrology is regulated by biota (Zalewski 2000). Vegetation cover on the floodplain can be an efficient ecohydrological tool for the regulation of floodplains hydraulics, river hydrology and optimization of nutrient retention (Wagner-Lotkowska *et al.* 2004). Floodplain vegetation influences water flow, matter sedimentation and also biomass production. A fundamental concept in ecohydrology is that plant physiology is directly linked to water availability. Where there is ample water, as in rainforests, plant growth is more dependent on nutrient availability. However, in semi--arid areas like most of Middle East and African countries, vegetation type and distribution relate directly to the amount of water that plants can extract from the soil. When insufficient soil water is available, a water-stressed condition occurs. Plant under water stress decreases both their transpiration and photosynthesis through a number of responses, including closing their stomata. This decrease in the canopy water flux and carbon dioxide flux can have an impact on surrounding climate and weather. Soil water content is a general term describing the amount of water present in the vadose zone, or unsaturated portion of soil below ground. Since plants depend on this water to carry out critical biological processes, soil water content is integral to the study of ecohydrology. Any attempt to improve water retention capacity of soil may assist in creating optimum water conditions for plant growth.

The uses of alternative water holding amendments and irrigation methods will become more important over time, especially in regions of reduced water availability such as most Middle East and African countries. Hydrogels are superabsorbents that absorb and store water hundreds of times their own weight, i.e. 400-1500 g water per dry gram of hydrogel (Johnson 1984a; Bowman, Evans 1999). Their performance is determined by the chemical properties of the hydrogel, such as molecular weight, formation conditions of the hydrogel, as well as the chemical composition of the soil solution or irrigation water. Water held in the expanded hydrogel is intended as a soil reservoir for maximizing the efficiency of plant water uptake. Commonly used hydrogels can be generally devided into three classes: natural polymers, semisynthetic and synthetic polymers (Mikkelsen 1994). Synthetic hydrogels usually consist of polyacrylamides (PAM) and polyvinylalcohols. Fully synthetic polymers are chemically cross-linked to prevent them from dissolving in solution (Mikkelsen 1994). The non-cross-linked PAM form is effectively used for soil erosion control, sediment reduction in surface waters and earthen canal bed stabilization (Woodhouse, Johnson 1991).

Hydrogel networks have been reported to improve aeration and drainage of the medium (Bearce, McCollum 1977), improve market life of container grown plant (Eikhof *et al.* 1974; Still 1976; Bearce, McCollum 1977), reduce the moisture stress of plants (Gehring, Lewis 1980) and improve seed coating (Pamuk 2004). Wallace and Wallace (1986) stated that the most favorable results for seed emergence and water infiltration generally came from an anionic polymer and a cationic polymer was less effective.

Hydrogels have been used to establish tree seedlings and transplants in the arid regions of Africa and Australia to increase plant survival (Specht, Harvey-Jones 2000; Save *et al.* 1995; Callaghan *et al.* 1988, 1989). Specht and Harvey-Jones (2000) found that less drought tolerant tree species had a much more favorable response to the application of hydrogels. *Flindersia brayleana* (Queensland maple) and *Dysoxylum muelleri* (Red bean) had increased overall dry weights when hydrogels were incorporated into the growing substrate, whereas the drought tolerant species of *Flindersia australis* (Australian teak) and *Grevillea robusta* (Silky oak) showed no significant increase in overall dry weight. In an experiment, irrigation was stopped for as few as six days, causing all of the control seedlings to die, as compared to the 57% and 71% survival rate of the hydrogel amended soil (Callaghan *et al.* 1989). Drought sensitive plants, such as *Petunia parviflora* (petunia), responded well to the hydrogels in dry conditions and increased flower numbers and dry weights (Boartright *et al.* 1997).

Callaghan *et al.* (1988, 1989) found that hydrogel amendments in sandy soils promoted seedlings survival and growth under arid conditions, while Viero *et al.* (2000) under similar conditions found only an increase in seedling growth when hydrogel was applied in combination with irrigation. Contrasting results may be related to the soil texture, thus hydrogel application in sandy soils promotes an increase in water retention capacity and plant water potential (Huttermann *et al.* 1999, Abedi-Koupai, Sohrab 2004), while in loamy and clay soils the effect may be negligible. The effect of an amendment of sandy soil with highly cross-linked polyacrylamide (Stokosorb K400) on the survival of *Pinus halepensis* (Aleppo pine) seedlings during water stress was investigated by Huttermann *et al.* (1999). Different concentrations of the hydrogel were added to sandy soils at 0.04, 0.08, 0.12, 0.20 and 0.40% weight by weight. The highest addition (0.4%) changed the water retention and its change in water potential with regard to its water content from typical sand to a loam or even silty clay. The survival rates in 0.4% hydrogel were doubled compared to no hydrogel amendments. The hydrogel also allowed for 19 days tolerating drought.

A hydrogel (Stokosorb K 410) effects on growth and ion relationships of salt resistant woody species, *Populus euphratica*, were studied by Chen *et al.* (2003). Addition of 0.6% hydrogel to saline soil has improved seedling growth (2.7 fold higher biomass) during a period of 2 years. Root length and surface area of treated plant had 3.5 fold more than those grown in untreated soil. It was reported that hydrogel treatment enhanced Ca^{+2} uptake and increased capacity of *Populus euphratica* to exclude salt (i.e. reduces contact with Na^+ and Cl^-). Witbooi and Esler (2004) evaluated the effect of different cultivation methods with addition of either organic mulch or a hydrogel (aquasorb), on seeding emergence of seven indigenous plant species in South Africa. Seedling emergence was higher in areas where seed and aquasorb were sown.

The use of increasing levels of the polymer (1, 2 and 4g kg^{-1}) influenced directly *Dendrathema grandiflorum* growth and the absorption of Ca and Mg (Marcato Sita *et al.* 2005). Probably these ions were retained in the polymer frame-

Table I. Physical and chemical characteristics of the soils.

Soil Texture	Depth	Soil particles (%)			Soil bulk density $cm^3\ cm^{-3}$	Soil actual density $cm^3\ cm^{-3}$	pH	EC $dS\ m^{-1}$
		Clay	Silt	Sand				
Sandy loam	0-30	15.2	32.4	52.3	1.19	2.69	6.7	4.1
	0-60	18	25.4	56.6	1.22	2.69	7.1	4.8
Clay	0-30	53	26	21	1.41	2.7	7.7	2.5
	0-60	48	27	25	1.38	2.6	7.9	2.8

work. Bharadwaj *et al.* (2007) reported water retained by polymers when mixed with sand ranged between 40 and 140 kg kg^{-1}. Water retained per kilogram of polymer increased with an increase in polymer concentration in the sand while undergoing desorption, but absorbed water decreased with polymer concentration during sorption, indicating an effect of hysteresis and absorption kinetics in the water absorption process. Sivapalan (2001) reported amount of water retained by a sandy soil at 0.03 MPa pressure was significantly increased by 23 and 95% with addition of 0.03 and 0.07% polymer, respectively. It was reported that water use efficiency for plants increased by 12 and 19% with the application of 0.03 and 0.07% polymer, respectively. Also, it was stated that the increase in water retention decreases the amount of water otherwise lost by deep percolation. When the pressure was increased from 0.01 to 1.5 MPa, the polymer enabled the sandy soil to retain more water.

Ligusrum ovalifolium

This vigorous oval leaf privet makes an excellent, pollution-tolerant hedge for an urban or suburban site. Thriving in sun or shade, the lustrous, dark green foliage provides a dense evergreen screen and can also be used as a backdrop for ornamental and feature plants. *Ligusrum ovalifolium* is one of the dominant trees in the city of Isfahan, in central Iran, particularly in the green belt zone of the city. Many efforts and costs have been allocated for maintenance and irrigation of this species by water trucks. Hence, it is important to find proper solutions to reduce the needed irrigation frequency, minimizing the cost of irrigation. To the knowledge of authors no information is available in the literature to study the effects of a hydrogel amendment on the field performance of *L. ovalifolium* under deficit irrigation.

The purpose of this paper is to investigate the application of a cross-linked hydrogel on soil water retention characteristics using the RETC computer program and the effects of a hydrogel amendment on the field performance of *L. ovalifolium* under deficit irrigation.

2. Materials and methods

For the laboratory experiments in this study, two soils, classified as clay and sandy loam, were used. The sandy loam and clay samples were collected from the upper soil layer (0-30 and 30-60 cm) in Bakhtiar-Dasht area and Research Station of Mahmoud-Abad, respectively, both located in the west of Isfahan. The soil samples were air-dried, mixed, crushed and sieved to less than 2 mm particle size. The physical and chemical characteristics of the soils are shown in Table I. It should be noted that the previous laboratory study indicated the better performance of sandy soils amended with hydrogel, in respect to water holding capacity, compared to the clay soils, (Abedi-Koupai, Sohrab 2004). However to extend the laboratory results, it was required to conduct field trials.

The soil amendment used was a hydrogel, Superab A200, produced by Rahab Resin Co., Ltd under license of Iran Polymer and Petrochemical Institute. The properties of Superab A200 are shown in Table II.

Laboratory trials

The soil water characteristics were determined in the laboratory using a pressure plate apparatus (Soil Moisture, ELE model). Triplicate samples of each soil containing different amounts of hydrogels in dry form (4 and 6 g kg^{-1} soil) were

Table II. The properties of Superab A200.

Properties		Values
Water content (%)		5-7
Density (g cm^{-3})		1.4-1.5
pH		6-7
Grain size (μm)		50-150
Maximum durability (year)		7
Molecular weight (g mol^{-1})		269
Water uptake capacity (g/g)	distilled water	220
	tap water	190
	NaCl 0.9%	45

placed on the pressure plate in three retaining rings (65 mm diameter and 30 mm height) and saturated with tap water (EC=0.2 dS m^{-1}) overnight. The desired pressure (0, 0.3, 1, 3, 5 and 15 bars) was then applied until outflow ceased and the soil water was considered to be in equilibrium with the applied pressure. The gravimetric water content for each treatment was determined by oven drying. The soil volumetric water content was then determined by multiplying the gravimetric water content by the ratio of the soil bulk density (Table I). The computer program, RETC (Retention Curve Program for Unsaturated Soils), was used for obtaining optimal model parameters for nonlinear equations with multiple parameters (Van Genachten *et al.* 1990). The parameters are deemed optimal in the sense that they provide the minimum least-square error between the estimated and measured values. The RETC program used the parametric models of Van Genuchten (Eq. 1) and Brooks- Corey (Eq. 2) to represent the soil water retention curve:

$$\Theta = \theta_r + (\theta_s - \theta_r)[1+(\theta_h)^n]^{-m} \quad (1)$$
$$\Theta = \theta_r + (\theta_s - \theta_r)\,(\alpha\, h)^{-\lambda} \quad (2)$$

Where Θ is the soil volumetric water content, θ_s is the saturated water content, θ_r is the residual water content, α is the inverse of air entry value, h is the soil matric suction, λ is the pore size distribution index, and n and m are fitting coefficients.

Available water content *(AWC)* is the amount of water released by a soil between field capacity *(FC)* and permanent wilting point *(PWP)*. The *AWC* was calculated by subtraction of *FC* and *PWP (AWC=FC-PWP)*. The term implies that the available water can be used by plants. Field capacity is defined as the amount of water retained by a soil after it has been wet thoroughly and drainage has become negligible. For practical purposes, the soil water content at FC is the upper limit of soil water availability and has been related to a suction of 0.3 bars (300 kPa). The permanent wilting point of a soil is generally defined as the soil water content below which plants wilt permanently. This point has generally been given as the lower limit of soil water availability and has been related to a suction of 15 bars (1500 kPa). Also, PWP was determined for field soil using the sunflower (*Helianthus annuus L.*) method (Cassel, Nielsen 1986). In this method, plants are grown in pots that are sealed to prevent water loss other than that by transpiration. They are irrigated until the third set of leaves appears at which time the irrigation stops. The plant kept in a low evaporation environment until all three sets of leaves wilt. In order to ensure the wilting is permanent, pots are placed in a humid environment overnight. If all leaves remain wilted, in the next morning, the soil water content is determined and considered as PWP.

Field trials

The field trial was conducted in Mahmoud-Abad Research Station located in Isfahan, Iran (Longitude 51º 35’ E and Latitude 33º 47´ N). The average annual rainfall at the nearest station (Isfahan University of Technology) is 134 mm and the average annual air temperature is 17.0 ºC. The experimental site has an arid climate and is 1580 m above sea level. The field trials were conducted as a split plot on the completely random blocks design in which the treatments were two irrigation regimes consisting of 33% and 66% evapotranspiration (*ETc*) and two different quantities of hydrogels, adding either 4 or 6 g kg^{-1} of hydrogels to the soil. Irrigation treatments were: a deficit irrigation (66% *ETc*) and a severe deficit irrigation (33% *ETc*) (Tognetti *et al.* 2005). The amount of hydrogel addition was selected according to previous experiments (Abedi-Koupai, Sohrab 2004). The control blocks had no hydrogels and were irrigated with 100% evapotranspiration (*ETc*). Seedlings of year-old, *L. ovalifolium* were transplanted in small basins with 3 meters between plants. Inside each basin a hole (80 mm diameter and 60 mm depth) was dug, and the seedling was placed in the center of the hole. The hole was filled with a mixture of soils and the polymers, with the exception of control in which soil was only added. The soil around the roots was packed by hand. The experiment was conducted with three replications. The crop water requirement was computed based on water use efficiency, the root depths of the plant, and the moisture deficiency of soil for different stages of growth. Irrigation was applied to meet 33%, 66% and 100% evapotranspiration (*ETc*).

Evapotranspiration (*ETc*) was calculated based on class A pan data as follows (James *et al.* 1982):

$$ET_0 = K_{pan}\,(E_p) \quad (3)$$
$$ET_c = K_c\, ET_0 \quad (4)$$

where ET_0 is potential evapotranspiration from a reference crop, K_{pan} is the pan coefficient, E_p is evaporation from a pan and K_c is a dimensionless plant coefficient. Based on local experiments, and K_{pan} and K_c were set at 0.7 and 0.6, respectively. Having the height of ET_c and the area of basin around each plant, the volume of water added to the soil using a flowmeter with resolution of 0.001 dm^3. Based on soil and pan data, the irrigation intervals were selected 5 days in active growth stages (spring and summer) and 7 days in the remaining months (fall and winter).

Irrigation regimes were conducted 2 weeks after the establishment of the plants. The growth indices of *L. ovalifolium* including height, shoot diameter and leaf area were measured at the beginning of planting and 12 months later at the end of the experiment.

Table III. Estimation of water retention parameters by RETC model.

Amount of polymer addition	Sandy loam			Clay		
	θ_r $cm^3\,cm^{-3}$	θ_s $cm^3\,cm^{-3}$	α $1\,cm^{-1}$	θ_r $cm^3\,cm^{-3}$	θ_s $cm^3\,cm^{-3}$	α $1\,cm^{-1}$
4	16.76	62.54	0.25	23.82	74.20	0.010
6	26.98	72.73	0.064	29.46	80.09	0.013
Control (without polymer)	5.05	37.57	1.09	20.35	61.15	0.007

θ_r is the residual water content, θ_s is the saturated water content,, α is the inverse of air entry value.

Multiple comparisons by the Post Hoc Least Significant Difference (LSD) test and analysis of variance for the various treatments were done by the statistical analysis package SAS™ (SAS 1998).

3. Results

Saturated water content (θ_s)

For each soil texture, Superab A200 application increased the volumetric water content (Table III). The increase in θ_s is proportional to the quantity of hydrogel application. The maximum value of θ_s occurred with the 6 g kg^{-1} application. The results indicate that in sandy loam soil, the value of θ_s is 1.9 times that of the control at maximum. In clay soils, the value of θ_s is 1.3 times that of the control at maximum redundant. Previous study revealed that the value of θ_s is 1.5 and 2.2 times that of the control in clay and sandy soils, respectively (Abedi-Koupai, Sohrab 2004). Hemyari and Nofziger (1981) and Bharadwaj *et al.* (2007) also reported that there was the greatest benefit to water holding through the addition of polymers in coarse-textured soils. Thus, the results indicate the proper performance of incorporating hydrogels in sandy soils compared to the clay soils.

Residual water content (θ_r)

The variations of (θ_r) in each soil texture are shown in Table III. The value of θ_r increased with the polymer addition and was larger with a larger polymer application. The increase of θ_r in sandy loam soil was found to be more than clay soil and 5.3 times that of the control. This most likely could be attributed to the sandy loam having less cation holding capacity compared with the clay. The cation exchange capacity of sandy soils may be as low as a few (1-5) milliequivalents per 100 g of soil, while clay soils may have cation exchange capacity more than 30 meq/100g soil (Danahue *et al.* 1977). As a result, the expansion of polymers and associated water adsorption increased. The increase of θ_r in clay soil was 1.5 times that of the control at maximum, with the application of 6 g kg^{-1}.

Air entry value (h_b=1/a)

Commonly the Water Retention Characteristic (WRC) changes sharply with the air entry value. Due to larger pore geometry in sandy loam soils, water is released under lower matric suction. In other words, the value of a is high. The value of a for the sandy loam and clay for the control is 1.09 and 0.007, respectively. As Table III shows, adding and increasing the amount of Superab A200 in sandy loam reduced the largest pores in the soils and the pressure required for water expulsion increased. Consequently, the value of a is reduced. In clay control soil, the air entry value was seen to increase, i.e. a decreased. Hydrogel addition to these soils may open the media, by forcing soil particles apart, thereby increasing aeration. Hence less pressure is needed for desorbing water and the value of a is increased.

Water Retention Characteristic Curve (WRC)

There is a statistically significant difference (95% confidence level) between Superab A200 application and without (control) and between the amount of polymer application in each soil texture and soil matric suction. The maximum increase was obtained at an application level of 6 g kg^{-1} (Fig. 1).

Available Water Content (*AWC*)

There is a statistically significant difference (95% confidence level) between the amount of Superab A200 application as well as between using the hydrogel application and not (control) for the two soil textures. The values of volumetric water content at field capacity (*FC*) and permanent wilting point (*PWP*) compared to the control are shown in Table IV for the two soils. The results indicate that the volumetric water content at *FC* for sandy loam is

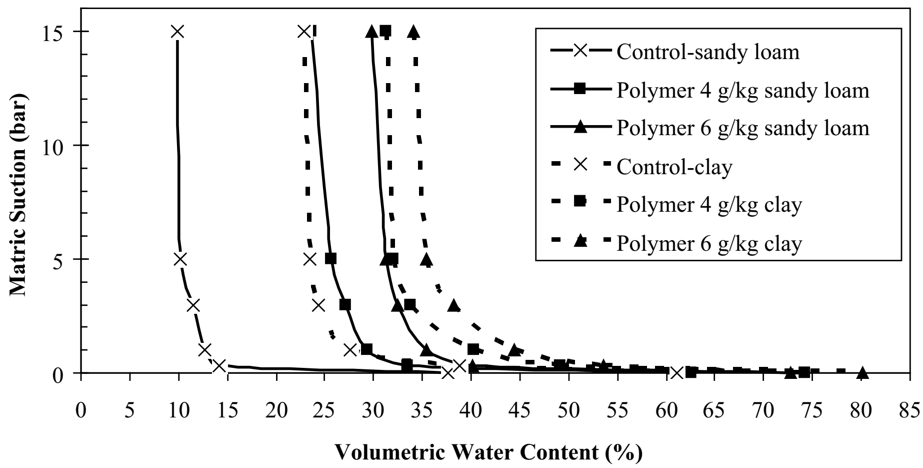

Fig. 1. Water retention characteristic curves in sandy loam and clay soil due to application of Superab A200.

increased 2.3 and 2.8 times that of the control by adding 4-6 g kg^{-1} hydrogel, respectively. The related values for *PWP* are 2.4-3 fold that of the control. The volumetric water content at *FC* for clay is increased 1.3-1.4 fold that of the control by adding 4-6 g kg^{-1} Superab A200, respectively. The related values for *PWP* is 1.4-1.5 fold that of the control.

The values of available water content (*AWC=FC-PWP*) compared to the control are shown in Table IV for the two soils. In the sandy loam, the soil *AWC* is 2.2 and 2.3 times that of the control by adding 4 and 6 g kg^{-1} of hydrogel, respectively. In clay soils, *AWC* is 1.1 and 1.2 times by adding 4-6 g kg^{-1} hydrogel as compared to the control (Table IV). This also indicates the good performance of coarse-textured soil incorporating hydrogel.

Number of days to reach Permanent Wilting Point (*PWP*)

There were marked responses in the number of days to permanent wilting point due to the polymer application and increases in polymer concentration. Samples containing 6 g kg^{-1} polymer had the maximum period to reach PWP (22 days) compared to the control samples (12 days). The related value for samples containing 4 g kg^{-1} polymer was 19 days.

Table IV. Volumetric water content (%) at *AWC* in soils compared to the control.

Control	Amount of polymer addition (g kg^{-1})	
	4	6
Sandy loam		
4.54	9.84	10.33
Clay		
15.90	17.89	19.40

Effects of polymer amendment on growth indices

The data were subjected to an analysis of variance to determine the effect of irrigation regimes, polymer addition, amount of polymer added, and the interaction between them (Table V).

Height

The results show that there are significant ($p<0.01$) effects of irrigation regime on the height. Multiple comparisons by Post Hoc Least Significant Difference (LSD) test indicated, there is a significant effect of 66% *ETc* on the height compared with 33% *ETc* (Table VI). The maximum effect of polymer addition on the height is related to 6 g kg^{-1}. However, there is no significant difference between polymer application of 4 g kg^{-1} and 6 g kg^{-1} with 66% *ETc* and untreated control (100% *ETc*). Thus, application of 4 g kg^{-1} Superab A200 could reduce the required water to the level of 33% less than that of the control.

Number of nodes

The results show that there are significant ($p<0.01$) effects of irrigation regime on the number of nodes. Multiple comparisons by Post Hoc Least Significant Difference (LSD) test indicated, there is a significant effect of 66% *ETc* on the number of nodes compared with the 33% *ETc* (Table VI). The maximum effect of polymer addition on the number of nodes is related to 6 g kg^{-1}. However, there is no significant difference between polymer application of 4 g kg^{-1} and 6 g kg^{-1} with 66% ETc and untreated control (100% *ETc*). Thus, application of 4 g kg^{-1} Superab A200 could reduce the required water to the level of 33% less than that of the control.

Table V. Analysis of variance of the growth indices of *Ligusrum ovalifolium*.

Variable factor	Degree of freedom	Least square average		
		Height (cm)	Number. of nuds	Leaf area (cm^2)
Replicate	2	27.79	67.89	4256.86
Irrigation regime (I)	1	2354.98**	8101.17 **	36153.6**
Different combinations (C)	5	506.43 **	3185.8 **	6075.86**
I×C	5	17.5	441.68	2999.55 **
Control against combinations	1	1111.02	6112.73	76335.72

** Significant ($p<0.01$)

the linear dependency of the frequency of irrigation to the AWC, the increasing of the AWC is proportional to the frequency of irrigation. This is an important issue where irrigation water is a scarce commodity, where short term drought is a possible cause of plant losses, and where the cost of irrigation maintenance must be minimized.

Leaf Area

The results show that there are significant ($p<0.01$) effects of irrigation regime on the leaf area. Multiple comparisons by Post Hoc Least Significant Difference (LSD) test indicated that there is a significant effect of 66% *ETc* on the leaf area compared with the 33% *ETc* (Table IV). The maximum effect of polymer addition on the leaf area is related to control, 6 and 4g kg^{-1}, respectively. However, there is no significant difference between polymer application of 4 g kg^{-1} and 6 g kg^{-1} with 33% *ETc* and 66% *ETc* and untreated control (100% *ETc*). Thus, application of 4 g kg^{-1} Superab A200 could reduce the required water to the level of 33% less than that of the control.

4. Discussion

The results seem to coincide with that of Johnson (1984b). The author mixed sand with different cross-linked polyacrylamides so as to produce a polymer concentration range of 0-2 g kg^{-1}. The results indicated that all polymers tested increased the field capacity (*FC*) of coarse sand by between 171 and 402%. Also, he showed that the permanent wilting point (*PWP*) of the control sand was reached between 2 and 3 days, in comparison with between 6 and 7 days for the 1 g kg^{-1} polymer treated sand and between 9 and 10 days for the 2 g kg^{-1} polymer treated sand. Enhancement of the number of days to the onset of wilting has been reported previously in growing systems amended with hydrogels (Gehring, Lewis 1980; Baasiri *et al.* 1986). It should be noted that the number of days to wilting point is independent estimate of plant performance.

Frequency of irrigation can be determined by dividing the amount of water to be depleted from the soil by the consumptive use per day. Hence, due to

The maximum effect of polymer addition on the height is due to the 6 g kg^{-1} application. However, there is no significant difference between the polymer applications of 4 g kg^{-1} and 6 g kg^{-1} with 66% *ETc* and the untreated control (100% *ETc*). Thus, application of 4 g kg^{-1} Superab A200 could reduce the required water to the level of 33% less than that of the control.

Our findings coincide with that of Allahdadi *et al.* (2005), who studied the impact of Superab A200 on *Zea mays* yield and yield components. They reported there was no significant difference between a polymer application of 200 kg ha^{-1} along with an irrigation interval of 7 days and the untreated control with an irrigation interval of 3 days.

The results seem to concord with that of Callaghan *et al.* (1988, 1989), who planted *Eucalyptus microtheca* (Eucalyptus) in Sudan with PAM and PVA hydrogels incorporated into sandy soil. The survival rate of *Eucalyptus microtheca* growing in the absence of irrigation doubled when hydrogels were added. In situations with reduced irrigation (deficit irrigation) rates, the survival rate was 1.4 and 1.6 times better with a hydrogel amendment (Callaghan *et al.* 1988, 1989).

The effects of applying hydrogels in soils may be summarized as follows:

- There was an increase of both the residual water content (θ_r) and saturated water content (θ_s) in the range of soil matric suction studied (0-15 bars).
- The application of 4 and 6 g kg^{-1} of Superab A200 addition in sandy loam soil enhanced the available water content by 2.2 and 2.3 times as compared to the control. The related value for

Table VI. The comparison of average growth indices for *Ligusrum ovalifolium* under reduced irrigation regimes and polymer amendment.

Index	Control	66% *ET*		33% *ET*	
		4 g kg^{-1}	6 g kg^{-1}	4 g kg^{-1}	6 g kg^{-1}
Height (cm)	11.31 ^{a}	8.51 ^{a}	12.75 ^{a}	N*	N*
Number of nuds	23.85 ^{a}	22.35 ^{a}	39.01 ^{a}	N*	N*
Leaf area (cm^2)	376.6 ^{a}	282.33 ^{bc}	331.57 ^{ab}	178.5 ^{d}	190.0 ^{d}

No significant difference ($p<0.01$) between treatments with the same sign. *N - no growth clay soil was 1.1 and 1.2 times. The results indicate much better performance of coarse-textured soil incorporating hydrogel.

- The number of days to permanent wilting point and growth indices is independent estimates of plant performance. There were marked responses in the number of days to permanent wilting point as a result of polymer application. However, higher application rates of polymers could not be justified in practice. The application of 4g kg^{-1} Superab A200 had a proper performance for *L. ovalifolium* and reduced the required water to at least 33% of the control. The saved water may be used to expand vegetation cover on the floodplain which is an efficient ecohydrological tool to regulate water circulation in the floodplain.
- The variations of soil hydraulic properties due to the addition of Superab A200 represented much clear by using RETC computer program.

Thus, application of hydrogels can result in significant reduction in the required irrigation frequency, particularly for coarse-textured soil (such as sandy soils). This is an important issue in arid and semi-arid regions of the world for enhancing the water management of coarse-textured soils.

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