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Impact of Super Absorbent Polymers (hydrogels) on Water Use Parameters of Plum Trees under Water Stress Conditions

Fadlallah[3], S. G., G. Abdel-Nasser[2], M. A. Aly[1], M. M. Harhash[1], A. M. ELSegieny[3]
1 Plant Production Dept., Faculty of Agriculture Saba Basha, Alexandria University
2 Soil and Agricultural Chemistry Dept., Faculty of Agriculture Saba Basha, Alexandria University
3 Horticulture Research Institute, Agricultural Research Center, Giza

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ABSTRACT: The present study was conducted during two successive seasons 2019 and 2020 on five years old "Kelsey" Plum trees (*Prunus salicina* L.), budded on Mariana rootstock. The trees were planted in sandy soil in a private orchard located in Salah Al-Abd Village, Bostan Area, West Nubaria, Behaira Governorate, Egypt (Lat. 30.598° and Long. 30.228°). The study was conducted to test the effect of irrigation practices;100, 80, and 60% of reference evapotranspiration (ET_0) and water retaining materials (hydrogel polymers) Barbary Plant, "BP" and Aqua Gool, "AG" at rates of 75, 100, and 125 g/tree in addition to the control treatment. The irrigation was controlled via the operating time using the drip irrigation system. The results revealed that fruit yield was improved by the application of AG and BP treatments. The treatments of AG125 and BP125 gave the highest significant values in yield and yield parameters as compared to the control (not treated trees). The increases over the control treatment were 25.65 and 27.84% for AG125 and 22.41 and 24.05% for BP125 in the 2019 and 2020 growing seasons, respectively. On the other side, the highest value of fruit yield and parameters was recorded for 100% of ET_0 treatment and then decreased with decreasing irrigation rate.

The calculated crop evapotranspiration (ETc) of Plum trees reached 774.1, 619.3, and 464.5 mm during the 2019 growing season for 100, 80, and 60% of ET0, respectively. The corresponding values for the 2020 growing season are 662.3, 529.8, and 397.4 mm, respectively. The applied irrigation water of Plum trees was 3251.13, 2600.90, and 1950.68 m^3/fed during the 2019 growing season for 100, 80, and 60% of ET0, respectively. The corresponding values were 2920.23, 2367.28, and 1813.06 m^3/fed, respectively, for the 2020 growing season. As for the irrigation water use efficiency (IWUE) of Plum trees, the GA125 and BP125 treatments were found to increase IWUE by about 26.63 and 21.57% over the control treatment in the first growing season, respectively while it was 27.78 and 23.32 %, respectively in the second growing season. The treatments in terms of water use efficiency came in descending order as follows GA125, BP125, BP100, GA100, BP75 then GA75. Irrigation water use efficiency was increased under irrigation deficit by about 13.52 and 12.90% for 80 and 60% of ET_0 in the 2019 growing season, respectively as compared to 100% of ET_0. The corresponding values for the 2020 growing season were 12.52 and 9.68%, respectively. Accordingly, the use of hydrogel as a water preservative and or deficient irrigation can be an appropriate strategy to obtain a good yield of Plum trees under conditions of water shortage, taking into account that the incomplete irrigation should be moderate, with the need to study its long-term effects on the strength of growth and productivity of trees.

Keywords: *Hydrogels, super absorbent polymers, Plum trees, water saving, water retaining materials*

INTRODUCTION

The Kelsey Plum (*Prunus salicina*) is one of the deciduous fruit trees which need low chilling requirements **(Gao *et al.*, 2001).** So, it is cultivated throughout the warmer parts of the world, e.g., in China, America, Europe, and the Kaukasus as well as Egypt. The cultivated area in the world was 2.6 million ha an annual production of 11.8 million tones with an average yield of 4.49 tons/ha **(Tareen *et al.*, 2020)**. China produced 56% of the world production (6,801,187 tonnes) followed by Romania (842,132 tonnes), Serbia with 430,199 tonnes, and Egypt, with 14,775 tonnes of production per year is ranked at 44 with an average of 13,197 kg/ha **(World Plum Production by Country, 2022)**.

Plum fruit has many advantages including being sweet, juicy, and edible, and it can be eaten fresh or dried or used in making other products or recipes like jams, compotes, mousse, pulp, candied fruit, frozen fruit addition to jelly products **(Miloseviae & Miloseviae, 2011)**. As a result of many nutritional and health properties, eating fruits reduces the risk of chronic diseases and limits the increase in body weight in general **(Boeing *et al.*, 2012)** and it works prevention and management of osteoporosis (**Igwe & Charlton, 2016**). Therefore, it is considered one of the most important nutritional means to prevent obesity and problems related to obesity disorders **(Siddiqui, 2017)**. In addition to the above mentioned, plum fruits have many positive effects that improve health, as the fruits contain anti-inflammatory, anti-cancer agents, anti-diabetic, and neuroprotective (**Dhalaria *et al.*, 2020)**. This shows that fruit not only provides better income opportunities for growers but is additionally pivotal to providing more healthy diets for consumers.

In Egypt water resources are limited and more than 95% of all freshwater resources from outside international borders are represented in the Nile River **(Amer *et al.*, 2017)**. In addition to many problems related to it and the possibility of a decrease in the amount of water that flows from it is very large. The scarcity of rainfall and irrigation water is a critical problem in arid and semiarid regions, where water is the determining factor for crop productivity and the cultivated area **(Han *et al.*, 2018).** In the same context, groundwater is a non-renewable resource, and reliance on it in irrigation operations is costly, especially for the owners of small farms. Soil water conservation techniques are the alternative, to stimulate, collect, store and conserve water for irrigation **(Mabhaudhi *et al.*, 2019)**.

Sandy soils with low productivity as a result of the weak structure, low humus content, and high rate of deep water and nutrient infiltration which affects soil-water plant relationships as well as nutritional status and accordingly plant production **(Rajakumar & Jayasree, 2016)**. Therefore, increasing the total amount of water that soil can hold and available water capacity and thus the amount of water that a plant can absorb from the soil is an important issue to increase the water use efficiency and sustainability. This can be achieved through soil amendment practices **(Smith, 2018)**. Many soil properties addition to moisture conservation the hydrogel can improve such as density, porosity, temperature, water holding capacity, CEC, etc., and biological properties like microbial environment. Agricultural hydrogel polymers are eco-friendly materials since they are naturally degraded over some time, and didn't leave any toxic residue in the soil and plants. Hence use of hydrogel as a soil conditioner will be a productive option for increasing sustainable agricultural productivity in case of soil water stresses **(Sri *et al.*, 2019)**. Agricultural systems that are less able to retain water are prone to reduced crop yield so in arid and semiarid areas soil amendments play a vital role in relieving water stress **(Yang *et al.*, 2022)**.

Hydrogel is a super absorbent polymer (SAP) that can absorb water hundreds of times its dry weight (up to 400-2000 g water g^{-1}) **(Yang *et al.*, 2014 & Guilherme *et al.*, 2015)**. Depending on its properties there are many uses for hydrogel polymers in the agricultural field to create a suitable growing environment for plants including insoluble water polymers, and soil remediation polymers. The most important hydrogel uses is to absorb water and soluble fertilizer and then release it to plants at the proper time **(Abobatta, 2018)**. Hydrogel is a soil conditioner that can retain water and nutrients in the soil for plants. Polymers are synthetic, water-absorbing monomers of high molecular weight. When soil moisture near the root zone of plants start to dry up hydrogel begins to release water and nutrient to the plants. The soil application of hydrogel led to many avails includes; increasing soil moisture-holding capacity, increase in pore size/number, increase in the stock of nutrients in the soil, and reduction in soil compaction **(Nirmala & Guvvali, 2019 & Herawati *et al.*, 2021)**. It has been found that the use of superabsorbent acrylate polymers (SAPs) in arid regions is a new technology that has been quickly adopted by farmers to reduce soil water loss, and increase crop yield **(Li *et al.*, 2014)** in many regions (**Han *et al.*, 2010, Sharma *et al.*, 2015 & Peng *et al.*, 2016)** by maintaining soil moisture content (**Chen *et al.*, 2016**) thus improves water use efficiency (**Liao *et al.*, 2016**).

Adding hydrogel amendment to soil increases tree growth and yield of Khasi mandarin **(Pattanaaik *et al.*, 2015a)** and Citrus limon **(Pattanaaik *et al.*, 2015b)** compared to the zero rates (control). Also, Banana growth parameters like the height of pseudostem and circumference, green leaves number, and assimilation area at the bunch shooting stage were significantly increased by applying hydrogel polymers **(Kassim *et al.*, 2017)**. Furthermore, applied polymers under different levels of water stress have an appositive effect on the growth, yield, and water use efficiency of "Washington Navel" orange trees **(Abo El-Enien & Moursi, 2019)**. Also, **Abdallah (2019)** found that the addition of polymers materials to sandy soil led to increasing the amount of available water that the soil can hold and reduced its loss in the depths. This reflected positively on the survival of guava seedlings that grew in sandy soil under water stress conditions compared to those which not added hydrogel polymers.

Thus, the objective of this study was to evaluate the effectiveness of synthetic water retention soil amendments (hydrogels), in separate or combined operations under water deficit irrigation, on yield, and water use parameters of Plum trees.

MATERIALS AND METHODS

1. Experimental plot

This study was carried out during two successive seasons 2019 and 2020, on five years old "Kelsey" plum trees (*Prunus salicina* L.), budded on Mariana rootstock. The trees were planted in sandy soil in a private orchard located in Salah Al-Abd Village, Bostan Area, West Nubaria, Behaira Governorate, Egypt (Lat. 30.598° and Long. 30.228°). The trees were spaced at 3×3.5 m apart (400 trees/fed.) and irrigated by the drip irrigation system. The fertilization program and other agricultural practices were the same for all trees.

The experimental site is characterized by a semi-arid climate; the weather is hot and dry from May to August. Some climatological data from the experimental site were taken for the NASA POWER (https://power.larc.nasa.gov/data-access-viewer/) and presented in Table (**1**).

2. The layout of the experiment

The experimental trees (105 trees) were selected as very similar in size and shape as possible and arranged in a split-plot design with 5 replicates, in which the irrigation represents the main factor and the water-retaining materials (Hydrogel) represent the subfactor. The selected trees are divided into three groups. Each group is irrigated with a water syringe representing a certain percentage of reference evapotranspiration (100%, as full irrigation), 80 and 60% of the ET_0). The seven hydrogel treatments (Three rates of both of AG and BP addition to control) with 5 replicates for each were distributed in each of the three irrigation groups.

3. The experimental treatments

3.1. Irrigation practices (main plots)

The irrigation treatments were full irrigation, FI (100% of the ET_0), moderate irrigation treatment, MI (80% of the ET_0), and stress irrigation treatment, SI (60% of the ET_0). The irrigation was controlled via the operating time and using 71 emitters/line (4L/hr). Each row of trees is 25 m in length with two lateral GR lines for each row of the trees with emitters spaced each 0.35 m. The amount of irrigation water was calculated as follows:

The amount of irrigation water = the number of drippers x dripper discharge (4L/hr) x operating time (minutes).

Table (1). Average of some climatic parameters for the experimental site during the growing seasons of Plum trees

Month	Ta C°	Tx C°	Tn C°	RHm %	Pe mm/month	U2 m/s	PS kPa	RA $MJ/m^2/day$	ET_0 mm/day
2019									
Jan	10.85	17.41	6.01	58.93	4.00	3.30	100.85	16.23	2.18
Feb	12.53	19.65	7.04	63.07	7.24	2.76	100.93	20.58	2.45
March	14.87	22.28	8.97	62.38	11.77	3.04	100.83	26.45	3.39
April	18.63	26.66	11.75	55.00	3.89	3.17	100.69	32.01	5.07
May	25.08	34.55	16.73	42.69	0.04	3.19	100.45	35.74	7.70
June	27.68	35.74	20.69	53.78	0.00	3.34	100.29	37.30	7.48
July	28.71	36.76	21.86	53.88	0.00	3.19	100.06	36.63	7.46
2020									
Month	**Ta C°**	**Tx C°**	**Tn C°**	**RHm %**	**Pe mm/month**	**U2 m/s**	**PS kPa**	**RA $MJ/m^2/day$**	**ET_0 mm/day**
Jan	12.15	17.35	8.03	71.36	31.64	3.27	101.24	16.23	1.71
Feb	13.12	19.42	8.43	70.78	28.32	2.68	101.11	20.68	2.16
March	15.54	23.14	9.71	64.58	2.06	3.23	100.57	26.65	3.45
April	18.16	25.70	11.81	63.41	86.07	2.73	100.63	32.16	4.33
May	22.48	31.25	15.15	58.30	0.04	3.09	100.61	35.82	6.14
June	25.42	33.80	18.06	54.00	0.21	3.13	100.32	37.32	6.99
July	27.79	36.14	20.56	57.38	0.00	3.19	99.97	36.57	7.19

3.2. Water retaining materials (subplots)

The Hydrogel polymers were "Barbary Plant G3", **BP** (40% Hydro polymer, 6.5% N, 4.8% P, 8.2% K and holding capacity at 300-500%) produced by Lucky Star TG., Egypt, and another one named "Aqua Gool, **AG** (~ 90% Hydro potassium polymer and hold capacity at 400-500%) Russian production. The polymers were added once in the last week of January in two trenches around the tree in both seasons. Three levels of each polymer were used as 75, 100, and 125 g/tree in addition to the control treatment (7 treatments).

4. Soil analysis:

Soil samples (0-30 and 30-60 cm, depth) were collected before the experiment for an analysis of some chemical and physical soil properties. Some physical and chemical properties and moisture content of the experimental site are presented in Tables (**2** and **3)** according to **Carter & Gregorich (2008).**

Table (2). Some physical and chemical properties of the experimental soil

Parameter	**Surface (0-30 cm)**	**Subsurface (30-60 cm)**	**Unit**
Mechanical Analysis			
Sand	94.32	94.01	%
Silt	5.68	5.99	%
Clay	-	-	%
Textural class	Sandy	Sandy	
pH (1:2, water suspension)	8.06	8.22	-
EC(1:2, water extract)	0.52	0.33	dS/m
Soluble cations			
Ca^{2+}	2.50	1.70	meq/l
Mg^{2+}	0.50	0.50	meq/l
Na^{+}	1.87	1.17	meq/l
K^{+}	0.33	0.13	meq/l
Soluble anions			
HCO_3^{-}	2.00	2.00	meq/l
CO_3^{-2}	0.00	0.00	meq/l
Cl^{-}	1.75	1.00	meq/l
SO_4^{-2}	2.10	0.30	meq/l
Available nutrients			
Nitrogen (N)	171	171	mg/kg
Phosphorus (P)	32	32	mg/kg
Potassium (K)	55	55	mg/kg

Table (3). Soil moisture constants for the experimental site

Soil depth (cm)	**Field capacity (%, w/w)**	**Wilting point (%, w/w)**	**Available water (%, w/w)**	**SP %(w/w)**
0-30	**8.0**	**3.0**	**5.0**	**15.0**
30-60	**7.5**	**3.0**	**4.0**	**13.0**
Average	**7.75**	**3.0**	**4.5**	**14.0**

5. Yield:

The producing yield (ton/fed) was expressed by multiplying the weight of fruits/tree (kg) which was attained at the harvest stage by the number of trees/fed.

6. Crop Water-Use Parameters

Systematic determination of several water parameters was carried out to provide basic information for the interpretation of experimental results. The following parameters were determined:

6.1. Reference Evapotranspiration (ET_0)

The reference evapotranspiration (ET_0) was calculated with the FAO Penman-Monteith equation (**Allen *et al.*, 1998)** according to the climatic data collected from NASA POWER. The equation is expressed as:

$$ET_0(\text{mm/day})=\frac{0.408\Delta(R_n\text{-}G)+\gamma\frac{900}{T+273}U_2\left(e_s\text{-}e_a\Delta\right)}{\Delta+\gamma\left(1+0.34U_2\right)}$$

Where:

ET_0 Reference evapotranspiration, mm day-1 ;
R_n Net radiation at the crop surface, MJ m-2 day-1;
G Soil heat flux density, MJ m-2 day-1 (Generally very small and assumed to be zero for daily calculations);
T Mean daily air temperature at 2.0 m height, C°;
U_2 Wind speed at 2 m height, m s^{-1};
e_s Saturation vapor pressure at 1.5 to 2.5 m height, kPa;
e_a Actual vapor pressure at 1.5 to 2.5 m height, kPa;
e_s - e_a Saturation vapor pressure deficit, KPa;
Δ Slope vapor pressure-temperature curve, $kPaC^{\circ-1}$; and
γ Psychrometric constant, $kPaC^{\circ-1}$

6.2. Crop Evapotranspiration (ETc)

The crop evapotranspiration (ETc) is the daily use of water by trees and is calculated from the following equation **(Allen *et al.*, 1998)**:

$$ET_c = K_c \times ET_0$$

Where:

Kc is the crop coefficient ranging from 0.4 (for the initial stage) to 0.95 (for the full development stage)

6.3. Crop Water Requirements

The crop water requirements were calculated according to the Penman-Monteith equation (**Allen *et al.*, 1998**) using the following equation (**Cuenca, 1989**):

$$ET_{drip} = K_r \times K_c \times ET_0$$

Where:

ET_{drip} is the crop water requirement under a drip irrigation system

Kr is the reduction factor that reflects the percent of soil covered by crop canopy, Kr can be calculated by the equation described in **Karmeli & Keller(1975)**:

$$K_r = \frac{GC}{0.85}$$

Where:

GC is the ground cover fraction (plant canopy area divided by soil area occupied by one tree, assumed as 0.7).

6.4. Applied Irrigation Water

The amount of applied irrigation water was calculated according to the following equation (**Vermeiren & Jopling, 1984**):

$$AIW = \frac{ET_{drip}}{(1\text{-}LR) \times E_i}$$

Where:

AIW is the depth of applied irrigation water (mm),

Ei is the irrigation efficiency of the drip irrigation system (assumed as 0.90)

LR is the leaching requirement used for salt leaching in the root zone depth (assumed as 0.15).

Irrigation time was calculated before an irrigation event by collecting the actual emitter discharges according to the equation given by **Ismail (2002)** as follows:

$$t(hr) = \frac{AIW \times A}{1000 \times q}$$

Where:

t is the irrigation time (hr),

A is the wetted area (m^2), and

q is the emitter discharge (m^3/hr).

6.5. Water Consumptive Use (CU)

The plant water consumptive use was calculated by the following formula:

$$CU(mm) = K_r \times K_c \times ET_0$$

Where: CU is the Plum trees' water consumptive use (mm/day).

6.6. Water Use Efficiency (WUE)

The Irrigation Water Use Efficiency (IWUE) was calculated according to **Sharma *et al.* (2015)** as follows:

$$IWUE(kg/m^3) = \frac{\text{Plum Trees Yield(kg/fed)}}{\text{Applied Irrigation Water}(m^3/\text{fed})}$$

7. Statistical analysis

All obtained data of the present study were statistically analyzed according to the design used by the **Statistix 10 (2019)** computer software program and were tested by analysis of variance. least significant difference at a 0.05 level of probability was used to compare the differences among the means of the various treatment combinations as illustrated by **Duncan (1955) and Gomez & Gomez (1984).**

RESULTS AND DISCUSSION

1. Plum Yield

The results related to the yield show a significant effect of irrigation level and hydrogel application treatments, in addition to the interaction between them, on the tree yield (kg/tree) and finally, the gross yield (ton/fed). The yield of the tree increased after the application of hydrogels as a result of the increase in the weight and number of fruits for each tree, which led to an increase in the gross yield (ton/fed) compared with the control treatment. Statistical analysis showed a significant increase in yield (ton/fed) as a result of adding amendment materials to the soil at the beginning of each season (Table 4). The maximum increase in yield reached (25.65 and 27.84%) when AG was added at 125g/tree and (22.41 and 24.05) when 125 g/tree were added from BP in the two seasons respectively.

Concerning the level of irrigation, the data showed that the yield decreased significantly when the irrigation water was reduced to 80 and then to 60% of ET_0, which caused the greatest decrease in the yield during the two seasons. The positive interaction between the irrigation level and the hydrogel addition treatments led to a reduction in the yield loss as a result of reducing the irrigation level to 80 and then to 60% level.

In this study, the increase in yield resulted from an increase in the number of fruits per tree and an increase in the weight of fruits (g). The yield increase may be due to, providing water in the root zone area during periods of shortage which ensures an easier transfer of water and nutrients to the plant, and increasing the rate of carbon dioxide absorption, which improves the process of photosynthesis and increases its outputs. As well as the storage of those products, thus improving plant growth dramatically and increasing biomass accumulation which reflects positively on the yield **(El-Hardy *et al.*, 2009 & Jamnika *et al.*, 2013)**. It can also be attributed to the soil being wet for a long time and increasing the microbial activity that also reduces the drop of fruit on account of water stress **(Pattanaaik *et al.*, 2015b)**. This explains what was mentioned by **Shivakumar *et al.*, (2019)** they reported that yield is determined by the overlap of several factors, the most important of which are the environmental factors, which include climate factors and soil factors, in addition to the physical and biological interactions that occur within the plant system which affects the process of photosynthesis, the transmission of its products, and the accumulation of those products inside the plant, especially in economic part.

These results were confirmed by **Abd El-Badea *et al.*,2011**, who reported that the application of hydrogel soil amendment (VH) affected yield attributes like total yield positively. In addition, many studies indicate the same effect of hydrogel applications under reduced irrigation water levels on a lot of crops, for instance, **Barakat *et al.*, 2015** found that the yield and yield parameters of bananas were increased when watered soil plants that were treated with 150g hydrogel/plant by 80% of IR. Furthermore, the maximum fruits number per tree of 'Khasi' mandarin was recorded by applied100 g of stock absorb hydrogel/tree **(Pattanaaik *et al.*, 2015a)** and the Citrus limon yield increased by 43% compared with the control when the soil was amended with 100g of stock absorb per tree **(Pattanaaik *et al.*, 2015b).** Additionally, these findings are consistent with the results of **Safavi *et al.*, 2016** on the pumpkin and banana. Also, **Kassim *et al.*, 2017** found that the plant yield (kg) and the yield (ton/fed) increased significantly by adding 1000 g/mat every year and increased more with 1500 g/mat every year. In addition, **Abdel-Aziz *et al.*, 2020** found a significant increase in 'Murcott' mandarin trees yield by the addition of hydrogel to the soil compared with that without hydrogel addition. In addition, increasing the used rate of hydrogel from 250 up to 750 g/tree significantly increased the yield compared to the control. On the same line, **Kumar Nika *et al.*, 2020** registered the positive effect of hydrogel application on yield.

Table (4). Effect of some water retaining materials (hydrogel) at different rate under different irrigation levels on yield of Kelsey plum trees during the 2019 and 2020 seasons

Irrigation levels	treatments	Average fruit weight(kg/tree)		Yield(Ton/Fed)	
		2019	2020	2019	2020
100	Control	13.51	13.16	5.40	5.26
	AG75	14.78	14.14	5.91	5.71
	AG100	15.83	15.33	6.25	6.12
	AG125	16.68	16.82	6.75	6.73
	BP75	15.06	14.46	6.02	5.76
	BP100	16.45	15.94	6.59	6.36
	BP125	16.72	16.18	6.66	6.47
80	Control	12.18	11.89	4.87	4.76
	AG75	13.13	12.89	5.25	5.17
	AG100	14.17	13.99	5.67	5.60
	AG125	15.23	14.92	6.09	5.99
	BP75	13.85	13.47	5.65	5.38
	BP100	15.21	14.98	6.08	5.99
	BP125	15.21	14.84	6.08	5.94
60	Control	9.09	8.66	3.63	3.46
	AG75	10.48	10.22	4.19	4.09
	AG100	11.17	10.94	4.47	4.37
	AG125	11.63	11.23	4.65	4.49
	BP75	10.05	9.91	4.02	3.96
	BP100	10.55	10.47	4.22	4.19
	BP125	10.73	10.71	4.65	4.28
	L.S.D	0.857^{***}	0.779^{***}	0.353^{***}	0.300^{***}
Irrigation	100	15.57	15.15	6.23	6.06
	80	14.14	13.85	5.67	5.55
	60	10.53	10.30	4.21	4.12
	L.S.D	0.344^{***}	0.286^{***}	0.092^{***}	0.139^{***}
treatments	Control	11.59	11.24	4.64	4.49
	AG75	12.79	12.42	5.12	4.99
	AG100	13.72	13.42	5.46	5.37
	AG125	14.51	14.32	5.83	5.74
	BP75	12.99	12.61	5.23	5.04
	BP100	14.07	13.80	5.63	5.51
	BP125	14.22	13.91	5.68	5.57
	L.S.D	0.495^{***}	0.450^{***}	0.204^{***}	0.173^{***}
Interaction	L.S.D	1.917^{*}	1.742^{*}	0.790^{*}	0.670^{*}

(AG 75,100 and125 (Aqua gool hydro polymer at 75,100 and 125 g/tree
– BP 75,100 and 125 (Barbary Plant hydro polymer at 75,100 and125 g/tree)

2. Crop water use parameters

2.1. Reference evapotranspiration

The reference evapotranspiration calculated according to the Penman-Montieth equation is illustrated in Tables (**5** and **6**). The data indicated that reference evapotranspiration was higher in the first season (1040.69 mm) than in the second season (877.79 mm). The difference between both seasons was due to the changes in climatic conditions.

2.2. Crop evapotranspiration

The calculated crop evapotranspiration of plum trees reached 774.1, 619.3, and 464.4 mm during the 2019 growing season for 100, 80, and 60% of ET0, respectively. The corresponding values for the 2020 growing season are 662.3, 529.8, and 397.4 mm, respectively. The difference between both seasons was due to the climatic conditions (Tables **5** and **6**).

The Kc values, used to calculate the crop evapotranspiration during the evaluated stages, were 0.40 to 0.95, according to **(Cotrim *et al.*, 2011)**. The values of Kc are illustrated in Tables (5 and 6) for the growing season of Plum trees.

The irrigation requirement of Plum trees is still not well investigated. A progressive crop coefficient (Kc) ranging from 0.40 to 0.95 was proposed to calculate crop water requirement (**De Azevedo *et al.*, 2003)**. Also, the crop coefficient is still under study because until now crop coefficient of Plum trees has not been defined and has little investigation.

The present study gave proposed values of Kc as described by the following equation:

$$Kc = -1E\text{-}06X^3 + 0.0004X^2 - 0.0322X + 1.1488 \qquad (R^2 = 0.9550)$$

Where X represents the days in the year.

Table (5). Monthly reference evapotranspiration and crop evapotranspiration during the 2019 growing season of Plum trees

Month	ET0 mm/month	ETc (mm/month)			Kc
		100%	80%	60%	
Feb	75.33	19.03	15.22	11.42	0.400
March	115.71	46.28	37.03	27.77	0.400
April	164.70	106.17	84.94	63.70	0.628
May	261.72	246.78	197.42	148.07	0.942
June	272.49	234.34	187.48	140.61	0.929
July	170.73	121.48	97.18	72.89	0.711
Total	1040.69	774.08	619.26	464.49	0.686

Table (6). Monthly reference evapotranspiration and crop evapotranspiration during the 2020 growing season of Plum trees

Month	ET0 mm/month	ETc (mm/month)			Kc
		100%	80%	60%	
Feb	59.79	23.91	19.13	14.35	0.400
March	116.63	48.49	38.79	29.09	0.411
April	143.38	106.52	85.22	63.91	0.737
May	208.37	197.95	158.36	118.77	0.950
June	235.94	209.60	167.68	125.76	0890
July	113.69	75.80	60.64	45.48	0.665
Total	877.79	662.28	529.82	397.37	0.685

2.3. Applied irrigation water

The applied irrigation water of Plum trees was 3251.13, 2600.90, and 1950.68 m^3/fed during the 2019 growing season for 100, 80, and 60% of the ET0, respectively. The corresponding values were 2920.23, 2367.28, and 1813.06 m^3/fed, respectively, for the 2020 growing season (Table 7).

Table (7). Applied irrigation water to Plum trees during the 2019 and 2020 growing seasons

Month	2019 growing season			2020 growing season		
	100%	80%	60%	100%	80%	60%
Feb	79.91	63.93	47.95	251.92	230.54	212.73
March	194.38	155.51	116.63	208.66	166.93	116.04
April	445.92	356.74	267.55	358.79	287.54	220.87
May	1036.46	829.17	621.88	666.19	532.85	400.53
June	984.25	787.40	590.55	973.07	779.68	584.76
July	510.20	408.16	306.12	461.60	369.74	278.13
Total	3251.13	2600.90	1950.68	2920.23	2367.28	1813.06

2.4. Water Use Efficiency (WUE)

Where water is a limiting factor for production, deficit irrigation can enhance WUE, so that the available water is better allocated. Water use efficiency (WUE) was calculated as the harvested yield (kg) per volume of irrigation water (m^3) according to FAO recommendations **(Doorenbos & Kassam, 1979)**. WUE is affected by polymer and the amount of applied water.

In the current study, the WUE at 80% and 60% of ET_0 was higher compared to 100% of ET_0 as the control treatment as shown in Table (8), which contains the values of the water use efficiency (IWUE and CWUE). The results indicated that the IWUE was affected by irrigation levels, in which the values decreased with increasing the irrigation level. The medium irrigation level (80% of ET_0) reached the highest value for both growing seasons. Irrigation water use efficiency (IWUE) was increased under irrigation deficit by about 13.52 and 12.90% for 80 and 60% of ET_0 in the 2019 growing season, respectively as compared to 100% of ET_0. The corresponding values for the 2020 growing season were 12.52 and 9.68%, respectively. Also, consumptive water use efficiency (CWUE) was more pronounced at 80% of ET_0 than 100% of ET_0 by 13.53 and 14.20% for the 2019 and 2020 growing seasons, respectively. Furthermore, With deficit irrigation, water productivity was 2.174 and 2.485 kg/m3 for the 2019 and 2020 growing seasons, against 1.915 and 2.179 kg/m3 for full irrigation (100% of ET_0), respectively. On the other side using the water retaining materials increase the water use efficiency (IWUE and CWUE) of Plume trees compared with untreated trees. the results in Table (8) showed that the GA125 and BP125 treatments were found to increase IWUE by about 26.63 and 21.57% over the control treatment in the first growing season respectively while it was 27.78 and 23.32 %, respectively in the second growing season. The treatments in terms of water use efficiency came in descending order as follows GA125, BP125, BP100, GA100, BP75 then GA75, and the last treatment was control. As for consumptive water use efficiency (CWUE), the data inducted that, soil addition with GA or BP hydrogels increased CWUE significantly compared to the control treatment in both seasons. The high CWUE values were achieved in the case of GA125 followed by BP125 in both seasons. The increase reached 26.03 and 27.8 over the control treatment for GA125 in the 2019 and 2020 seasons respectively while it was 21.54 and 23.13 over the control in the case of BP125 in the 2019 and 2020 seasons respectively.

WUE is affected by polymer and the amount of applied water. This trend is true because the increasing values are due to the high productivity of Plum trees per unit of irrigation water (m^3) under irrigation deficit treatment compared with full irrigation. As shown in this study, deficit irrigation especially offers an alternative to conventional irrigation without any detrimental effect on fruit quality. Considering the large increase in WUE, deficit irrigation has shown to be practical for Plum production. In this regard, the present results support the theory that the deficit irrigation shortage in general, is appropriate to make Plum tree production more sustainable **(Razouka *et al.*, 2013)**. However, Irrigation of Plum trees is necessary to ensure high fruit yields and favorable fruit quality. The replenishment of the water use by ET_C to 100% as it can be calculated by standard methods is the most solid way to ensure the high productivity of the Plum trees.

In General, this result agreed with those of **Razouka *et al.* (2013)** who reported that water use efficiency (WUE) was improved significantly when deficit irrigation was applied to peach; plum, and almond, in the plum tree, the irrigation with 75% or 50% ET_0 increased WUE significantly by the same amplitude by an average of 41% compared to 100% ET_0. In the opposite of these results, **Kassim *et al.*(2017)** found that the highest WUE value was achieved when banana plants were irrigated with 100% of recommended irrigation water compared with 80% or 75 % of recommended irrigation water. This difference in the results may be due to the different varieties or plant species.

Increasing the productivity of trees as a result of adding polymers per unit of irrigation water (m^3) improves water use efficiency. When added both hydrogel granules led to an increase in the irrigation interval considerably for Plum trees this means increasing WUE, especially with the rate of 125g. The productivity of the Plum can be increased by about 23.5 or 26.5 percent by the application of 125g of BP or AG respectively per tree in comparison to the control according to the results of this study. These results agree with those reported by **Salvin *et al.*,2000; Ibrahim 2003; Ibrahim *et al.*, 2012 and Kassim *et al.*, 2017)** on the banana.

Improvement of WUE may be attributed to the available water formed in the root zone, but not the amount of applied water **(Kassim *et al.*, 2017)** and this is due to the BP and AG as soil conditioners able to retain water and plant nutrients. The hydrogel releases water and nutrient to the plants when the surrounding soil near the root zone of plants starts to dry up. This also increases the nutrient use efficiency of soil treated with polymers. Hence, the application of hydrogel in well-drained, gravelly, and sandy soil was found to be effective in increasing the yield of Plum trees. It also increases the WHC of the soil, which provides a conducive atmosphere for better growth of roots in well-drained and sandy soils and ultimately increases Plum yield.

Table (8). Irrigation water use efficiency and consumptive water use efficiency of Plum trees during the 2019 and 2020 growing season

Irrigation % of ET_0	IWUE kg/m^3	CWUE kg/mm	IWUE kg/m^3	CWUE kg/mm
	2019		2020	
The main effect of irrigation				
100	1.915	8.042	2.076	9.153
80	2.174	9.130	2.336	10.453
60	2.162	9.079	2.277	10.383
LSD 0.05	0.0307**	0.127**	0.048**	0.202**
The main effect of materials				
Control	1.799	7.558	1.908	8.553
GA75	1.995	8.381	2.131	9.560
GA100	2.131	8.949	2.292	10.282
GA125	2.278	9.525	2.438	10.931
BP75	2.028	8.517	2.147	9.627
BP100	2.176	9.138	2.340	10.491
BP125	2.187	9.186	2.353	10.531
LSD 0.05	0.052**	0.218**	0.060**	0.272**
Interaction effect				
LSD 0.05	0.0812**	0.3865**	0.0885*	0.4690*

CONCLUSION

The addition of hydrogel to the soil of plum trees had a significant effect on the yield and its components in trees irrigated with full water needs, as well as those grown under water stress. In water-stressed trees, yield increased by both types of hydrogel during the two study seasons when used at all rates, and it was the best at 125 g/tree. It is also evident from the results that the water use efficiency is affected by the level of irrigation on the one hand and the other hand by soil amendments with hydrogel. The efficiency of irrigation water use increased with the reduction of the irrigation level from 100% to 80 and then to 60% ET_0, although The replenishment of the water use by ETc to 100% as it can be calculated by standard methods is the most solid way to ensure the high productivity of the Plum trees. On the other hand, the addition of hydrogel had a significant effect on increasing the efficiency of irrigation water use, especially with the high rate of 125 gm/tree. It is assumed that these effects were due to the hydrogel's ability to absorb and re-release nutrients and water. Accordingly, the use of hydrogel as a water preservative and or deficient irrigation can be an appropriate strategy to obtain a good yield of Plum trees under conditions of water shortage, taking into account that the incomplete irrigation should be moderate, with the need to study its long-term effects on the strength of growth and productivity of trees.

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الملخص العربي

تأثير البوليمرات فائقة الامتصاص (الهيدروجيل) على معايير استخدام المياه لأشجار البرقوق تحت ظروف الإجهاد المائي

صفوت جبريل فضل الله[3] ، جمال عبد الناصر خليل[2] ، محمود احمد علي[1] ، محمد محمد حرحش[1] و امال
محمود السجيني[3]

1 قسم الإنتاج النباتي – كلية الزراعة سابا باشا – جامعة الإسكندرية

2 قسم الأراضي والكيمياء الزراعية – كلية الزراعة سابا باشا – جامعة الإسكندرية

3 معهد بحوث البساتين – مركز البحوث الزراعية – الجيزة

أجريت الدراسة الحالية خلال موسمين متتاليين 2019 و 2020 على أشجار البرقوق صنف كلزى "Kelsey" (*Prunus salicina* L.) البالغة من العمر خمس سنوات ، والمطعومة على اصل ماريانا. زرعت الأشجار في تربة رملية في بستان خاص يقع في قرية صلاح العبد ، منطقة البستان ، غرب النوبارية ، محافظة البحيرة ، مصر (خط العرض 30.598° وخط الطول 30.228 °) أجريت الدراسة لاختبار تأثير ممارسات الري ب 100 او 80 او 60٪ من البخر–نتح المرجعي (ET_0) واضافة المواد الحافظة للمياه او الهيدروجيل (بربى بلانت "BP" و اكواجول "AG") بمعدلات 75 و 100 و 125 جم / شجرة بالإضافة إلى معاملة الكنترول (بدون إضافات). تم التحكم في الري من خلال وقت التشغيل باستخدام نظام الري بالتنقيط. أظهرت النتائج التي تم الحصول عليها من الدراسة الحالية للموسمين المتتاليين 2019 و 2020 أن محصول البرقوق قد تحسن عن طريق تطبيق معاملات AG و BP حيث أعطت معاملات AG125 و BP125 أعلى قيم معنوية للمحصول مقارنة بمعاملة المقارنة (الأشجار غير المعالجة). كانت الزيادات عن معاملة المقارنة 25.65 و 27.84٪ لمعاملة AG125 و 22.41 و 24.05٪ لمعاملة BP125 في موسمي النمو 2019 و 2020 على التوالي ، على الجانب الآخر ، سجلت أعلى قيمة لمحصول الثمار في معاملة الري 100٪ ET_0 ثم تناقص المحصول مع تناقص معدل الري.

بلغ معدل البخر نتح المحسوب لأشجار البرقوق 774.1 و 619.3 و 464.5 ملم خلال موسم النمو 2019 بالنسبة 100 و 80 و 60٪ من ET_0 على التوالي. القيم المقابلة لموسم الزراعة 2020 هي 662.3 و 529.8 و 397.4 ملم على التوالي. وبلغت مياه الري المضافة لأشجار البرقوق 3251.13 و 2600.90 و 1950.68 متر مكعب / فدان خلال موسم النمو 2019 مقابل 100 و 80 و 60٪ من ET_0 على التوالي. كانت القيم المقابلة لموسم النمو 2020 هى 2920.23 ، 2367.28 ، 1813.06 متر مكعب / فدان ، على التوالي. أما بالنسبة لكفاءة استخدام المياه لأشجار البرقوق ، فقد وجد أن المعاملتين GA125 و BP125 أعطت زيادة فى IWUE بحوالي 26.63 و 21.57٪ عن معاملة الكنترول في موسم النمو الأول 2019، على التوالي بينما كانت الزيادة 27.78 و 23.32٪ على التوالي في موسم النمو الثاني 2020. جاءت المعاملات من حيث كفاءة استخدام المياه بترتيب تنازلي على النحو التالي GA125 و BP125 و BP100 و GA100 و BP75 ثم GA75. أشارت النتائج إلى زيادة كفاءة استخدام مياه الري (IWUE) في ظل عجز الري بنحو 13.52 و 12.90٪ في 80 و 60٪ من ET_0 في موسم النمو 2019 ، على التوالي مقارنة بـ 100٪ من ET_0. كانت القيم المقابلة لموسم االنمو 2020 هي 12.52 و 9.68٪ على التوالي.

وفقًا لذلك ، يمكن أن يكون استخدام الهيدروجيل كمادة حافظة للمياه و/ أو الري الناقص استراتيجية مناسبة للحصول على محصول جيد من أشجار البرقوق في ظل ظروف نقص المياه ، مع الأخذ في الاعتبار أن الري غير الكامل يجب أن يكون معتدلاً ، مع الحاجة إلى دراسة تلك التأثيرات طويلة المدى على قوة نمو وإنتاجية الأشجار.