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Effect of Superabsorbent Polymer Application on Soil Hydraulic Properties, Growth, Yield, and Water Use Efficiency of 'Early Sweet' Grapevine (*Vitis vinefera*) under Different Irrigation Levels

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THE present investigation were conducted over two consecutive seasons (2020 and 2021) in a private vineyard located at El-Sadat Region, Menoufiya Governorate, Egypt on 'Early Sweet' grapevines. Two field experiments were carried out, the first to assess the impact of superabsorbent polymer (SAP) on soil hydraulic properties. The second experiment to assess the effect of SAP on the growth, quality, yield, and water use efficiency of 'Early Sweet' grapevines under different levels of irrigation water, where the soil was treated with 900, 600, 300, or 0 g SAP/vine/season, and different levels of irrigation (100%, 80%, and 60% ETc). The results of the first experiment showed an improvement in the hydraulic properties of the soil, which increased with increasing SAP doses, which can reduce the amount of irrigation water. The results of the second experiment revealed that the percentage of bud burst was increased gradually by decreasing irrigation water level and increasing SAP doses. As for bud fruitful, 80% ETc recorded the highest values using the application of 900 and 600 g SAP doses. Moreover, the application of 900g SAP under 80% ETc gave the highest values of growth parameters (shoot length, leaves number/shoot, total leaf surface area/vine, coefficient of wood ripening, chlorophyll content and leaf mineral constituents). Furthermore, the results showed that the physical and chemical characteristics of berries and clusters were increased by increasing SAP doses under 80% ETc. Concerning the yield and water use efficiency, the application of 900g SAP under 80% ETc gave the highest significant values.

Keywords: Deficit irrigation, Superabsorbent polymer, 'Early Sweet' grapevines, Water use efficiency, Yield, Quality.

Introduction

In the conditions of climate change, water scarcity is regarded as a key limitation that poses a threat to crop productivity, particularly in arid and semi-arid countries (Iglesias & Garrote, 2015 and Mahmoud et al., 2020a). Irrigation is crucial for food security and economic growth in the Mediterranean region, which faces a major challenge due to frequent and severe droughts caused by climate change especially in the coastal regions (Mahmoud et al., 2020b and Mahmoud et al., 2022). Currently, 70% of the available freshwater on Earth is being used by agriculture, yet roughly 35% of this is lost due to leaky irrigation systems and ineffective irrigation water management (Chartzoulakis & Bertaki, 2015). In Egypt, agriculture consumes roughly 80% of available water resources (Swelam et al., 2022) and since the average annual rainfall is decreasing, most agricultural production is mostly dependent

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on irrigation and limited water resources. Accordingly, the constraints imposed by climate change require adaptive and effective irrigation management and associated modern technologies to minimize its impacts. In order to encourage water-saving agriculture, it is imperative to use an integrated system that uses water-efficient irrigation and agronomic water-saving practices (Flörke et al., 2018 and Mekonen et al., 2022).

First, deficit irrigation (DI) is among the strategies widely studied for sustainable water saving and optimizing water use efficiency (WUE) (Coyago-Cruz et al., 2019). It has been demonstrated that regulated deficit irrigation, particularly when used on fruit trees and vines, increases both water production and growers' earnings. In this respect, many countries have shifted from irrigating crops in order to satisfy their evapotranspiration requirements (ETc) or full irrigation (the conventional norm), to deficit irrigation (DI) strategies, which involve reducing the amount of water provided to the crop during the growing season. But in most cases, DI induces a gradual water deficit, due to the depletion of soil water reserves, accompanied by a reduction in harvestable yields, especially in soils with a significantly low water storage capacity (Fereres & Soriano, 2007).

Second, using water-saving methods to address this issue has generated a lot of interest in researching hydrogels for use in agro-agricultural applications. These materials enhance the physical qualities of soil, boost irrigation efficiency, and rationalise irrigation water use (Cerasola et al., 2022 and Oladosu et al., 2022). Superabsorbent polymers (SAP, Hydrogel, and Polymers), new water-saving materials, and soil conditioners have been widely adopted in agriculture in the advanced countries of the world. They are powdered polymers produced from hydrophilicity containing carboxylic acid, carboxamide, hydroxyl, amine, imide groups and so on, which have a high-water absorption capacity. The crosslinks present in the chain prevent its complete dissolution with the enormous capability of absorbing and retaining water or aqueous solutions and can absorb and retain up to hundreds of times their weights. SAP plays an important role in supporting plant growth and performance in limited irrigation environments, enhancing nutrient retention and delaying fertilizer dissolution, improving the effectiveness of water application and optimum use of water sources, and improving water retention and increasing soil drainage (Han et al., 2010). Its usage in agriculture serves a number of key objectives, including enhancing soil water status and overcoming dry spells to reduce the harm brought on by water stress. SAP application is known to enhance the amount of water available to plants' roots for absorption, by enhancing the soil's capacity to hold water (Liu & Chan, 2015).

The production of grapes in Egypt has remarkably increased in the past 10 years. New varieties have become popular in the newly reclaimed areas of the Egyptian Deserts, particularly early ripening cultivars such as 'Early Sweet', which ripens in the third week of May. The fruits of this cultivar are seedless, greenish yellow with aromatic flavor. This cultivar has great potential for exportation to European and Arabic Markets. Overall, global warming is influencing grapevine development, as demonstrated by variations in phenology and earlier harvests reported around the world (Webb et al., 2007). In order to maximize water productivity (production / unit of consumed water), modern irrigation management is moving away from an emphasis on production per unit of soil area (Fereres & Soriano, 2007). The adoption of the proposed SAP in cultivation could thus represent a promising solution for the rationalization of water resources, especially in desert areas (Cannazza et al., 2014). Although 'Early Sweet' is considered one of the most important grape cultivars in Egypt, there is less concern about the irrigation regime and the effect of water availability on plant growth and the composition of the juice from this variety.

The objective of this study is to: 1) evaluate the effectiveness of different levels of SAP on some soil hydraulic properties and 2) assess its impact under a deficit irrigation regime on vegetative growth, yield quality and water use efficiency of the 'Early Sweet' grapevine under desert condition.

Materials and Methods

Experimental conditions

Field experiments were conducted over three consecutive seasons (2019, 2020, and 2021), the work in the 1st season was considered a preliminary trial and then the results were tracked during the 2nd and the 3rd seasons, in a private vineyard located at El-Sadat Region, Menoufiya Governorate, Egypt (300 22 30" N and 300 30 1"E). The chemical and physical properties of the soil and irrigation water are shown in Tables

1 and 2. The soil texture of the experimental site was sandy soil. Semiarid Mediterranean climate with hot, dry summers and moderate winters characterizes the region. Seven-year-old ‘Early Sweet’ grapevines grafted on Freedom rootstock were the target of this study. The distances were 2 m between vines and 3 m between rows with a planting density of 700 vines/fed, grown under a drip irrigation system and supported by the Spanish Parron System, the vines were pruned to 96 buds per vine (10 canes ×8 buds/cane in addition to 8 spurs × 2 buds /spur). The vines were covered by polyethylene sheets. Normal cultural practices (e.g., fertilization, weed control, girdling, and pruning) were carried out following the typical requirements of the area.

Experimental treatments
The superabsorbent polymer (SAP)

The SAP hydrogel is a water-saving material and has been widely adopted in agriculture. SAP materials are hydrophilic networks that can absorb and retain huge amounts of water. The SAP used in this study is Stockasor 660 Type, Cross-linked poly potassium co-(acrylic resin polymer) co- (granular polyacrylamide hydrogel) that was manufactured by the Evonik Company. The polymer base of polyacrylic acid consists of super absorbers, which have the appearance of free-flowing white granules that are insoluble in water- and swell to gel upon contact with an aqueous solution (pH 7). On both sides of the vines, SAP was added in the soil at a depth of 30 cm under drip irrigation lines on February during the three seasons at four doses (SAP1 : 900, SAP2 : 600, SAP3 : 300, and SAP4 : 0 g / vine/season).

Irrigation treatments (I)

The drip irrigation system was comprised of two lateral lines per row with 8 adjustable discharge emitters/vine (4L/h).

During the three years, the reference evapotranspiration (ET0) was calculated according to the FAO Penman-Monteith method (Allen et al., 1998) using CROPWAT model v.8.0 based on the agro-metrological data for the study area. The daily maximum and minimum temperature, relative humidity, and other climate factors (wind speed, precipitation, and solar radiation) were collected from the automatic meteorological station located near the experimental site. ET0 was determined based on the Blaney–Criddle Equation (Rolbiecki, 2018).

$$ET0 = n * [p * (0.437 * t + 7.6) - 1.5]$$

Where:

n: number of days per month;

p: evaporation coefficients,

t: average monthly air temperature (°C).

The Kc (crop coefficient) values were

TABLE 1. Chemical and physical properties of the experimental soil.

Chemical properties									
Ec	**pH**	**Cations (meq/L)**				**Anions (meq/L)**			
dSm^{-1}	**1: 2.5**	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**HCO$_3^-$**	**Cl$^-$**	**SO$_4^{--}$**	**CO$_3^{--}$**
2.03	8.08	5.2	2.6	12	0.5	5	12	2.7	0.6
Physical properties									
Sand %	**Clay %**	**Silt%**	**Texture**		**FC %**	**WP %**	**Bulk density g/m^3**		
92.31	4.295	3.36	Sandy		13.77	6.65	1.435		

TABLE 2. Chemical properties of the irrigation water

pH	**Ec**	**Cations (meq /L)**				**Anions (meq / L)**		
	dS/m	**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**HCO$_3^-$**	**Cl$^-$**	**CO$_3^-$**
7.31	1.2	6	0.7	0.75	4.55	1.6	0.4	10

calculated from the leaf area index (LAI)/Kc relationship, as previously described by Netzer et al. (2009):

$$Kc = -0.0283 * LAI^2 + 0.3547 * LAI + 0.0775$$

The irrigation water that grapevines needed was determined by crop evapotranspiration (ETc) which was determined monthly from the product of ET0 and Kc and differed according to each phenological stage according to Williams et al. (2003) and the following equation:

$$ETC = Kc * ET0$$

There were three distinct irrigation levels evaluated: (i) (I1) the irrigation to satisfy maximum crop water requirements through the entire growing season at 100% ETc; (ii) (I2) a slight deficit irrigation and it represents at 80% ETc; (iii) (I3) a deficit irrigation and it represents at 60% ETc. The total amounts of irrigation water applied in the irrigation levels in this study are shown in Table 3.

Experiment parts

In this study, two field experiments were carried out:

Experiment I: Effect of SAP on the soil hydraulic properties

The authors conducted a preliminary experiment to see how the superabsorbent polymer (SAP) affects the soil hydraulic properties (field capacity, welting point, and available water). Firstly, soil moisture content was determined gravimetrically in the soil samples that were taken at successive 15 cm depths to a 60 cm depth from four locations (under and between the emitters and laterals) in treatment (I1) (100% ETc). Then sandy soil was mixed with the concentrations of SAP (900, 600, 300 and 0 g) to study the effect of SAP on soil hydraulic properties under ETc 100%. Soil samples were collected just before irrigation and 6 hours after irrigation to estimate evapotranspiration rates according to Allen et al. (1998). Soil hydraulic properties were determined for four depths up to 60 cm at the beginning of the experiment during all seasons. The average values for 2020 and 2021 seasons are presented in Table 4.

Experiment II: Effect of SAP under different irrigation levels on Early Sweet grapevines

The effect of SAP at four doses (SAP 1:900, SAP 2:600, SAP 3: 300, and SAP 4: 0 g / vine/ season) was evaluated under three irrigation levels (100% ETc, 80% ETc and 60% ETc) on bud behavior, vegetative growth, physical and chemical characteristics of berries, clusters characteristics, yield and water use efficiency (WUE).

Experimental design

The experimental design for first experiment was one way randomized block, while for second experiment was split plot, and the three irrigation levels occupied the main plots.

TABLE 3. Irrigation water requirements (I, m^3 fed^{-1} $season^{-1}$) at 100%, 80%, and 60%ETc.

	Season 2019			Season 2020			Season 2021		
	I1 (100%)	I2 (80%)	I3 (60%)	I1 (100%)	I2 (80%)	I3 (60%)	I1 (100%)	I2 (80%)	I3 (60%)
Total	3710.2	2968.1	2226.1	3816.3	3052.7	2291	3601.4	2881.7	2160.0

TABLE 4. Field capacity (FC), welting point (WP), and available water (AW) for the two growing seasons.

	2020			2021		
	FC (%)	WP (%)	AW (%)	FC (%)	WP (%)	AW (%)
0-15	13.5	6.5	7.0	12.5	6.04	6.46
15-30	13.8	6.7	7.1	12.9	6.23	6.67
30-45	13.6	6.6	7.0	13.2	6.38	6.82
45-60	14.2	6.9	7.3	13.7	6.62	7.08
Mean	13.78	6.68	7.1	13.08	6.32	6.76

Measurements

Soil hydraulic properties

Soil samples were taken with a screw auger. Soil hydraulic properties were determined for four depths to 60 cm depth during all seasons. Soil hydraulic properties which were determined were, Field capacity (FC), welting point (WP), and available water (AW)**.**

Bud behavior

The percentage of bud burst and bud fruitful were calculated as follows:

$$\text{Budburst } (\%) = \frac{(\text{No.of burst buds} \times 100)}{\text{Total No of buds/vine}}$$

$$\text{Bud fruitful } (\%) = \frac{\text{Fruitful buds} \times 100}{\text{Total No.of burst buds/vine}}$$

Vegetative growth

Physical characteristics and total chlorophyll content

The following morphological studies were conducted at harvest time on four fruitful buds per shoots of each considered vines. Shoot length (cm), leaves number/shoot, and total leaf surface area of the vine (m^2) measured by multiplied average leaf area (using a leaf area meter, Model Cl 203, U.S.A), by the average number of leaves/shoot and then by the number of shoots/vine. The coefficient of wood ripening was taken at the end of the growing season according to Belal et al. (2022). Leaf total chlorophyll content (SPAD) was measured at harvest time in the mature leaves on the 6th and 7th nodes by using a nondestructive Minolta chlorophyll meter SPAD 502.

Leaf mineral constituents

The leaves opposite to the clusters were taken at full bloom (Ali et al., 2018). Leaf content of N, P and K percentages were estimated according to the methods described by Pregl (2013), Snell & Snell (1967), and Jackson (1973), respectively.

Physical and chemical characteristics of the berries

Representative random samples of 30 clusters/treatment were collected when clusters reached the maturity stage (TSS% 17-18%). Average berry weight (g), size (cm^3), and firmness was measured by using Push/Pull (Dynamometer Model DT 101) and the results were expressed as (g/cm^2). The shattering percentage was determined for the stored clusters for seven days later at room temperature (28 to 32 °C). Shattering percentage was calculated by dividing the weight of shattered berries by the initial weight of the cluster. Berry juice measurements: Total soluble solids (TSS %) using a hand refractometer and titratable acidity (TA) (%) (AOAC, 2006). The ratio of TSS/TA was calculated.

Clusters characteristics and Yield

The following characteristics were determined: The average number of clusters/vine, average cluster weight (g), yield/vine (kg/vine), and yield/fed (kg /fed.) were determined at harvest time.

Water use efficiency (WUE)

The crop water use efficiency (WUE) was calculated as the ratio between the harvested yield (kg/fed) and the total amount of water applied (m^3/fed) as reported by Medrano et al. (2015).

$$\text{WUE} = \frac{\text{yield}}{\text{Applied irrigation water}}$$

Statistical analysis

Analysis of variance (ANOVA) was conducted in JMP Pro version 16 (SAS Institute, Cary, NC, USA). The effect of SAP doses on soil hydraulic properties was analyzed using one-way ANOVA. The combinations of superabsorbent polymer (SAP) doses and irrigation levels (I) were designed as a split plot with two factors; SAP doses (four levels) and irrigation levels (three levels). Tukey's method was used to compare means among the samples. Differences were significant when p-values were less than 0.05%. Principal component analysis (PCA) was employed to analyze the relationships among the parameters already analyzed.

Results

Effect of superabsorbent polymer (SAP) doses on the soil hydraulic properties

Because of the importance of the soil hydraulic properties such as field capacity (FC), welting point (WP), and available water (AW) on water, air, and nutrients availability for plants, sandy soil was mixed with various concentrations of SAP (900, 600, 300, and 0 g) to study the effect of SAP on soil hydraulic properties under the maximum water requirements through the entire growing season at 100% ETc. The results in Table 5 show the effect of SAP application doses on the soil hydraulic properties (field capacity, welting point, and available water), which generally resulted in a remarkable change in these properties. Both the field capacity and the available water of soil significantly increased as a result of the addition of SAP application doses compared to the control in both seasons. As the application doses of SAP were increased, it was found that both the field capacity and the amount of water available increased, in particular with the greatest influence resulting from the 900 g SAP treatment. Regarding the welting point, in the 2020 season, no significant differences between treatments were observed, however in 2021, the variances were significant, particularly with the greatest influence resulting from the 900 g SAP dose.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on bud behavior of 'Early Sweet' grapevines (bud burst and bud fruitful)

The results in Table 6 reveal that the percentage of bud burst was increased gradually by decreasing irrigation water level and increasing SAP doses. The bud burst percentage was surpassed using the SAP application doses under 60% and 80% ETc compared to the full irrigation requirement. Moreover, the results revealed that the bud burst under 60% ETc increased compared to 80% ETc without significant differences between them, with the greatest influence resulting from the 900 g SAP treatment in both seasons. Table 6 also shows that the bud fruitful percentage was increased by using the application of SAP doses under different irrigation levels, especially with a high application dose (900 g) in both seasons, and the percentage of the bud fruitful with SAP doses can be arranged in the following descending order: 900 > 600 > 300 compared to the control. Also, 80% ETc recorded the highest values of bud fruitful% using the application of 900 and 600 g SAP doses compared to the control in first season.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on vegetative growth of 'Early Sweet' grapevines

Physical characteristics and chlorophyll content

The vine growth parameters (shoot length, leaves number/shoot, total leaf surface area of the vine, and coefficient of wood ripening) were affected by SAP application doses under different irrigation levels (Table 7). Regarding shoot length, there was no significant differences were observed among SAP application doses under irrigation levels in both seasons. However, with the increase in water deficit (60% ETc), decreasing in shoot length was observed with decreasing SAP doses. The lowest value of this growth parameter was detected in the control under 60% of the irrigation requirement. As for leaves number/shoot, the highest values were achieved with 80% ETc with the highest rate of SAP (900g), while the lowest values were recorded in the control which received 60% ETc in both seasons. Likewise, in the case of the total leaf surface area of the vine, the 900 g SAP treatment under 80% ETc gave the highest values of total leaf surface area/vine. On the contrary, the lowest values were recorded in the control which received 60% ETc in the two seasons. Shifted to the coefficient of wood ripening, it was noticed that the differences were not statistically significant in both seasons. Regarding the total chlorophyll content, Table 7 demonstrates that no significant changes were observed across treatments in the both seasons.

TABLE 5. Effect of superabsorbent polymer (SAP) doses on soil hydraulic properties.

Treatments	Field capacity %	Welting point %	Available water%
		2020	
SAP1	26.77 ± 0.229 a	7.00 ± 0.229 a	19.76 ± 0.017 a
SAP2	21.27 ± 0.187 b	6.96 ± 0.237 a	14.31 ± 0.061 b
SAP3	17.27 ± 0.428 c	6.85 ± 0.047 a	10.42 ± 0.061 c
SAP4 (Control)	13.78 ± 0.106 d	6.68 ± 0.071 a	7.10 ± 0.77 d
		2021	
SAP1	27.57 ± 0.056 a	7.21 ± 0.032 a	20.36 ± 0.052 a
SAP2	21.91 ± 0.131 b	7.17 ± 0.021 a	14.74 ± 0.480 b
SAP3	17.79 ± 0.163 c	7.06 ± 0.114 a	10.73 ± 0.259 c
SAP4 (Control)	13.08 ± 0.114 d	6.32 ± 0.053 b	6.76 ± 0.200 d

*Different letters represent significant differences by Tukey's honesty test ($p \leq 0.05$). Each season was analyzed separately.
SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season.

TABLE 6. Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on bud behavior of 'Early Sweet' grapevines, bud burst % (A) and bud fruitful % (B).

	Treatments	SAP1	SAP2	SAP3	SAP4 (control)
			2020		
Bud burst %	I1	63.94 ± 0.158^{b-e}	61.76 ± 0.379^{cde}	59.67 ± 0.673^{e}	60.85 ± 0.520^{de}
	I2	71.59 ± 0.355^{abc}	70.37 ± 0.210^{abcd}	67.62 ± 0.16^{a-d}	65.43 ± 0.38^{a-e}
	I3	75.31 ± 0.065^{a}	72.48 ± 0.195^{ab}	70.66 ± 0.028^{a}	69.32 ± 0.13^{a-e}
Bud fruitful %	I1	41.32 ± 0.261^{abc}	39.16 ± 0.115^{bcd}	37.82 ± 0.019^{cde}	36.55 ± 0.038^{de}
	I2	43.81 ± 0.063^{a}	42.33 ± 0.072^{ab}	36.87 ± 0.052^{de}	34.84 ±0.052^{ef}
	I3	37.56 ± 0.068^{cde}	36.54 ± 0.092^{de}	35.31 ± 0.044^{def}	31.55 ± 0.066^{f}
			2021		
Bud burst %	I1	62.84 ± 0.061^{de}	62.85 ± 0.064^{de}	60.80 ± 0.134^{e}	60.92 ± 0.123^{e}
	I2	73.12 ± 0.182^{ab}	72.65 ± 0.193^{ab}	69.55 ± 0.048^{bc}	67.34 ± 0.064^{cd}
	I3	76.93 ± 1.057^{a}	75.65 ± 0.094^{a}	73. 76 ± 0.256^{ab}	70.55 ± 0.007^{bc}
Bud fruitful %	I1	42.56 ± 0.043^{abc}	40.39 ± 0.099^{cde}	37.92 ± 0.016^{def}	34.78 ± 0.024^{fg}
	I2	45.71 ± 0.014^{a}	44.53 ± 0.012^{ab}	40.23 ± 0.087^{cde}	38.53 ± 0.015^{abc}
	I3	41.66 ± 0.017^{bcd}	39.82 ± 0.026^{cde}	36.80 ± 0.022^{ef}	32.60 ± 0.093^{g}

*Different letters represent significant differences by Tukey's honesty test ($p \leq 0.05$). Each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

However, the maximum total chlorophyll content was obtained by using a high dose of SAP (900 g) under the application of 80% ETc, as compared to the control, while the lowest content was observed with the control under 60% ETc.

Leaf mineral constituents

Data in Table 8 show the effect of SAP application doses under different irrigation levels on N, P, and K contents in the leaves of 'Early Sweet' grapevines. Generally, results showed that the leaf nutrient contents were increased with increasing application doses of SAP under 80% ETc and the 900 g SAP gave the highest contents compared to the other treatments. While the lowest contents were detected in the control under 60% ETc.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on physical and chemical characteristics of berries of 'Early Sweet' grapevines

Berry physical characteristics

It was clear from Table 9 that adding SAP at 900 and 600 g under 80% ETc gave the highest significant values of berry weight and size compared with the control in the two studied seasons. However, the lowest values were detected by the control with increasing water deficit (60% ETc), especially in the 2020 season. Concerning berry firmness, data presented also in Table 9 show that 60% ETc recorded the highest values compared to 100% ETc by the application of SAP doses in both seasons, and the descending order of irrigation requirement as follows: 60 >80 >100%. Concerning berry shattering %, results revealed that the highest significant values were detected in the control under 100% ETc (negative effect). Contrariwise, the lowest values were detected by 300 g SAP treatment under 60% ETc (positive effect) in both seasons.

Berry chemical characteristics

The berry chemical characteristics, such as TSS (%), TA (%), and TSS/acid ratio, were examined as the quality criteria in Table 10. In general, increasing TSS% and TSS/acid ratio were observed with increasing SAP application doses. Data presented also that 60% and 80% ETc recorded the highest values of TSS, and TSS/acid ratio compared to 100% with the application of SAP doses in both seasons. The maximum value

TABLE 7. Effect of superabsorbent polymer (SAP) under different irrigation level (I) on vegetative growth of 'Early Sweet'.

	Treatments	SAP1	SAP2	SAP3	SAP4 (Control)
2020					
Shoot length (cm)	I1	189.4 ± 0.01^{abc}	192.6 ± 0.05^{abc}	200.2 ± 0.04^{a}	205.4 ± 0.08^{a}
	I2	196.7 ± 0.04^{ab}	193.6 ± 0.05^{abc}	189.8 ± 0.03^{abc}	185.3 ± 0.08^{abcd}
	I3	183.6 ± 0.02^{abcd}	175.8 ± 0.11^{bcd}	171.6 ± 0.06^{cd}	165.3 ± 0.12^{d}
Leaves number/ shoot	I1	24.66 ± 0.030^{cd}	24.66 ± 0.012^{cd}	26.68 ± 0.008^{c}	35.33 ± 0.008^{a}
	I2	35.76 ± 0.040^{a}	33.68 ± 0.003^{a}	31.85 ± 0.017^{ab}	28.65 ± 0.011^{bc}
	I3	31.60 ± 0.003^{ab}	26.66 ± 0.014^{c}	25.33 ± 0.014^{c}	20.33 ± 0.012^{d}
Total leaf surface area (m^2)	I1	$10.56 \pm 0.176^{a-e}$	$10.670 \pm 0.430^{a-e}$	$11.54 \pm 0.288^{a-d}$	12.20 ± 0.110^{ab}
	I2	13.16 ± 1.180^{a}	12.30 ± 0.360^{ab}	11.96 ± 0.028^{abc}	$10.93 \pm 0.481^{a-e}$
	I3	$9.83 \pm 0.520^{b-e}$	9.40 ± 0.320^{cde}	8.80 ± 0.660^{de}	8.44 ± 0.451^{e}
Coefficient of wood ripening (%)	I1	82.0 ± 0.014^{a}	83.0 ± 0.010^{a}	85.0 ± 0.020^{a}	83.0 ± 0.017^{a}
	I2	86.0 ± 0.030^{a}	85.0 ± 0.021^{a}	84.0 ± 0.020^{a}	80.0 ± 0.071^{a}
	I3	84.0 ± 0.024^{a}	88.0 ± 0.031^{a}	82.0 ± 0.073^{a}	80.0 ± 0.080^{a}
Chlorophyll content (SPAD value)	I1	42.30 ± 1.185^{a}	43.85 ± 2.230^{a}	44.64 ± 1.360^{a}	45.92 ± 2.176^{a}
	I2	49.11 ± 0.718^{a}	47.87 ± 0.792^{a}	46.26 ± 0.285^{a}	43.33 ± 0.030^{a}
	I3	46.54 ± 1.233^{a}	45.73 ± 2.152^{a}	43.63 ± 1.088^{a}	41.26 ± 2.057^{a}
2021					
Shoot length (cm)	I1	191.6 ± 0.10^{ab}	195.1 ± 0.06^{ab}	203.7 ± 0.21^{a}	209.1 ± 0.15^{a}
	I2	201.1 ± 0.18^{a}	196.5 ± 0.01^{ab}	195.3 ± 0.052^{ab}	191.1 ± 0.06^{ab}
	I3	186.3 ± 0.04^{abc}	186.5 ± 0.07^{abc}	$175.\ 0 \pm 0.14^{bc}$	163.1 ± 0.33^{c}
Leaves number/ shoot	I1	26.66 ± 0.023^{bc}	27.62 ± 0.046^{abc}	30.00 ± 0.063^{abc}	33.67 ± 0.006^{ab}
	I2	36.30 ± 0.006^{a}	35.08 ± 0.012^{ab}	30.66 ± 0.014^{abc}	26.66 ± 0.020^{bc}
	I3	31.00 ± 0.034^{abc}	28.66 ± 0.012^{abc}	24.00 ± 0.031^{c}	23.67 ± 0.011^{c}
Total leaf surface area (m^2)	I1	10.40 ± 0.230^{abc}	10.80 ± 0.152^{abc}	$11.93 \pm 0.548^{a\ b}$	11.50 ± 0.173^{abc}
	I2	12.86 ± 1.020^{a}	11.90 ± 0.435^{ab}	10.03 ± 0.698^{abc}	10.85 ± 0.633^{abc}
	I3	9.76 ± 0.553^{bc}	9.23 ± 0.218^{bc}	8.73 ± 0.218^{c}	8.60 ± 0.808^{c}
Coefficient of wood ripening (%)	I1	84.0 ± 0.030^{a}	84.0 ± 0.023^{a}	86.0 ± 0.020^{a}	86.0 ± 0.023^{a}
	I2	87.0 ± 0.025^{a}	85.0 ± 0.031^{a}	85.0 ± 0.025^{a}	85.0 ± 0.032^{a}
	I3	83.0 ± 0.024^{a}	82.0 ± 0.021^{a}	81.0 ± 0.017^{a}	80.0 ± 0.009^{a}
Chlorophyll content (SPAD value)	I1	43.64 ± 0.160^{bcd}	44.75 ± 0.186^{bcd}	$45.93 \pm 0.698^{a-d}$	44.48 ± 0.080^{bcd}
	I2	51.21 ± 1.688^{a}	49.44 ± 0.718^{ab}	48.33 ± 1.082^{abc}	42.56 ± 1.140^{cd}
	I3	47.75 ± 1.120^{abc}	46.82 ± 0.048^{abc}	44.73 ± 0.066^{bcd}	40.88 ± 0.156^{d}

*Different letters represent significant differences by Tukey's honesty test ($p \leq 0.05$). Each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

TABLE 8. Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on leaf mineral constituents of 'Early Sweet' grapevines.

	Treatments	SAP1	SAP2	SAP3	SAP4 (control)
			2020		
N%	I1	1.76 ± 0.098^{a}	1.86 ± 0.319^{a}	1.80 ± 0.076^{a}	1.85 ± 0.129^{a}
	I2	1.95 ± 0.055^{a}	1.93 ± 0.210^{a}	1.86 ± 0.120^{a}	1.83 ± 0.088^{a}
	I3	1.71 ± 0.169^{a}	1.69 ± 0.045^{a}	1.67 ± 0.008^{a}	1.62 ± 0.037^{a}
P%	I1	0.25 ± 0.045^{abc}	0.25 ± 0.015^{abc}	0.21 ± 0.015^{abc}	0.25 ± 0.011^{abc}
	I2	0.31 ± 0.032^{a}	0.28 ± 0.041^{ab}	0.26 ± 0.020^{abc}	0.24 ±0.017^{abc}
	I3	0.18 ± 0.008^{bc}	0.17 ± 0.012^{bc}	0.17 ± 0.017^{c}	0.15 ± 0.005^{c}
K%	I1	1.35 ± 0.029^{ab}	1.36 ± 0.018^{ab}	1.34 ± 0.012^{ab}	1.33 ± 0.020^{ab}
	I2	1.41 ± 0.020^{a}	1.38 ±0.020^{ab}	1.37 ± 0.015^{ab}	1.30 ± 0.008^{b}
	I3	1.32 ± 0.014^{ab}	1.31 ± 0.008^{b}	1.31 ± 0.005^{b}	1.30 ± 0.035^{b}
			2021		
N%	I1	1.78 ± 0.060^{a}	1.81 ± 0.010^{a}	1.86 ± 0.176^{a}	1.87 ± 0.117^{a}
	I2	1.95 ± 0.081^{a}	1.92 ± 0.143^{a}	1.88 ± 0.245^{a}	1.83 ± 0.056^{a}
	I3	1.70 ± 0.057^{a}	1.68 ± 0.234^{a}	1.67 ± 0.052^{a}	1.64 ± 0.103^{a}
P%	I1	0.25 ± 0.006^{abc}	0.24 ± 0.020^{abc}	0.22 ± 0.010^{bcd}	0.25 ± 0.008^{abc}
	I2	0.30 ± 0.014^{a}	0.29 ± 0.017^{a}	0.27 ± 0.012^{ab}	0.24 ± 0.015^{abc}
	I3	0.20 ± 0.017^{cd}	0.19 ± 0.015^{cd}	0.16 ± 0.008^{d}	0.15 ± 0.005^{d}
K%	I1	1.36 ± 0.018^{abc}	1.37 ± 0.024^{abc}	1.35 ± 0.008^{abc}	1.32 ± 0.011^{bc}
	I2	1.41 ± 0.010^{a}	1.39 ± 0.021^{ab}	1.36 ± 0.020^{abc}	1.33 ± 0.011^{abc}
	I3	1.33 ± 0.017^{abc}	1.33 ± 0.017^{abc}	1.31 ± 0.010^{c}	1.30 ± 0.005^{c}

*Different letters represent significant differences by Tukey's honesty test ($p \leq 0.05$). Each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

of the TSS/acid ratio in both seasons was obtained under 80% ETc treatment with the highest dose of SAP (900 g). In both seasons, a decline in TA% was observed concurrent with an increase in TSS%.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on clusters characteristics, yield, and water use efficiency of 'Early Sweet' grapevines

The results in Table 11 show that the average number of clusters and cluster weight were increased with increasing SAP doses and irrigation levels, and the increases in these parameters generally paralleled with the increase of the SAP doses compared to the control in both seasons. Concerning the effect of irrigation levels on the average cluster number, data revealed that 80% ETc recorded the highest values compared to 60% and 100% with the application of SAP doses in both seasons. Moreover, the highest significant values were found in the treatment of SAP at 900 g under 80% ETc in both seasons. On the contrary, the lowest average clusters number was recorded with 60% ETc irrigation without SAP amendment in both seasons. Concerning the effect of irrigation levels on the average cluster weight, the data

TABLE 9. Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on berry physical characteristics of 'Early Sweet' grapevines

Treatments	SAP1	SAP2	SAP3	SAP4	(Control)
			2020		
Berry weight (g)	I1	6.39 ± 0.01^{c}	6.41 ± 0.013^{bc}	6.43 ± 0.005^{ab}	6.39 ± 0.006^{c}
	I2	6.47 ± 0.011^{a}	6.45 ± 0.005^{ab}	6.40 ± 0.014^{bc}	6.38 ± 0.008^{cd}
	I3	6.41 ± 0.012^{bc}	6.39 ± 0.005^{c}	6.36 ± 0.006^{cd}	6.33 ± 0.012^{d}
Berry size (cm^{3})	I1	5.76 ± 0,030^{cde}	5.81 ± 0.012^{bcd}	5.81 ± 0.008^{bcd}	5.77 ± 0.008^{cde}
	I2	5.92 ± 0.040^{a}	5.88 ± 0.003^{ab}	5.85 ± 0.017^{abc}	5.75 ± 0.011^{de}
	I3	5.80 ± 0.003^{bcde}	5.76 ± 0.014^{cde}	5.72 ± 0.014^{de}	5.71 ± 0.012^{e}
Firmness (g/cm^{2})	I1	306.66 ± 6.009^{d}	308.33 ± 7.264^{d}	320.00 ± 2.886^{d}	326.66 ± 4.409^{d}
	I2	375.00 ± 5.773^{abc}	368.33 ± 4.409^{bc}	358.33 ± 6.009^{c}	371.66 ± 1.666^{bc}
	I3	383.33 ± 4.409^{ab}	380.00 ± 2.886^{abc}	376.66 ± 1.666^{abc}	398.33 ± 4.409^{a}
Berry shattering (%)	I1	24.34 ± 0.093^{b}	24.10 ± 0.076^{bc}	23.47 ± 0.059^{c}	25.8 ± 0.208^{a}
	I2	19.86 ± 0.147^{e}	20.19 ± 0.021^{e}	21.22 ± 0.198^{d}	24.12 ± 0.049^{bc}
	I3	18.85 ± 0.178^{f}	18.35 ± 0.043^{f}	17.51 ± 0.313^{g}	18.22 ± 0.041^{fg}
			2021		
Berry weight (g)	I1	6.66 ± 0.010^{ab}	6.65 ± 0.006^{abc}	6.60 ± 0.026^{bc}	6.46 ± 0.015^{e}
	I2	6.69 ± 0.018^{a}	6.68 ± 0.016^{ab}	6.58 ± 0.015^{cd}	6.49 ± 0.015^{e}
	I3	6.47 ± 0.014^{e}	6.47 ± 0.017^{e}	6.50 ± 0.014^{de}	6.51 ± 0.010^{de}
Berry size (cm^{3})	I1	5.85 ± 0.023^{b}	5.92 ± 0.046^{b}	5.96 ± 0.063^{ab}	5.97 ± 0.006^{ab}
	I2	6.10 ± 0.006^{a}	6.08 ± 0.012^{a}	5.92 ± 0.014^{b}	5.90 ± 0.020^{b}
	I3	6.00 ± 0.034^{a}	5.99 ± 0.012^{ab}	5.90 ± 0.031^{b}	5.87 ± 0.011^{b}
Firmness (g/cm^{2})	I1	306.66 ± 1.666^{b}	311.66 ± 6.009^{b}	315.00 ± 5.000^{b}	323.33 ± 3.333^{b}
	I2	383.33 ± 6.666^{a}	378.33 ± 3.333^{a}	373.33 ± 1.666^{a}	368.33 ± 3.333^{a}
	I3	388.33 ± 3.333^{a}	381.66 ± 1.666^{a}	375.00 ± 5.000^{a}	373.33 ± 3.333^{a}
Berry shattering (%)	I1	20.67 ± 0.049^{d}	20.95 ± 0.079^{d}	22.83 ± 0.103^{c}	26.45 ± 0.075^{a}
	I2	18.35 ± 0.029^{f}	19.57 ± 0.266^{e}	20.78 ± 0.143^{d}	24.93 ± 0.143^{b}
	I3	18.31 ± 0.072^{f}	18.15 ± 0.029^{f}	17.82 ± 0.036^{f}	18.33 ± 0.065^{f}

*Different letters represent significant differences by Tukey's honestly test ($p \leq 0.05$).Each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

TABLE 10. Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on berry chemical characteristics of 'Early Sweet' grapevines.

Treatments	SAP1	SAP2	SAP3	SAP4	(Control)
2020					
TSS (%)	I1	16.73 ± 0.185^{b-e}	16.50 ± 0.251^{cde}	16.40 ± 0.100^{de}	16.33 ± 0.176^{e}
	I2	18.00 ± 0.288^{a}	17.83 ± 0.202^{a}	17.63 ± 0.185^{ab}	17.40 ± 0.100^{abc}
	I3	17.93 ± 0.233^{a}	17.60 ± 0.152^{ab}	17.46 ± 0.088^{ab}	17.30 ± 0.057^{a-d}
TA (%)	I1	0.610 ± 0.010^{abc}	0.630 ± 0.015^{ab}	0.643 ± 0.023^{a}	0.656 ± 0.008^{a}
	I2	0.530 ± 0.018^{c}	0.540 ± 0.020^{bc}	0.566 ± 0.008^{abc}	0.570 ± 0.015^{abc}
	I3	0.543 ± 0.021^{bc}	0.550 ± 0.028^{bc}	0.573 ± 0.014^{abc}	0.583 ± 0.016^{abc}
TSS/TA	I1	27.43 ± 0.153^{bcd}	26.19 ± 0.242^{cd}	25.68 ± 0.795^{d}	25.54 ± 0.546^{d}
	I2	33.65 ± 1.724^{a}	33.15 ± 1.692^{a}	31.14 ± 0.272^{abc}	30.56 ± 0.768^{a-d}
	I3	33.11 ± 1.462^{a}	32.16 ± 1.638^{ab}	30.49 ± 0.620^{a-d}	29.70 ± 0.786^{a-d}
2021					
TSS (%)	I1	17.23 ± 0.120^{def}	16.83 ± 0.166^{ef}	16.66 ± 0.088^{f}	16.43 ± 0.120^{f}
	I2	18.73 ± 0.288^{a}	18.46 ± 0.088^{ab}	18.20 ± 0.152^{abc}	17.60 ± 0.100^{cde}
	I3	18.50 ± 0.120^{a}	18.50 ± 0.288^{a}	18.93 ± 0.066^{a}	17.66 ± 0.166^{bcd}
TA (%)	I1	0.583 ± 0.016^{a-d}	0.613 ± 0.006^{abc}	0.633 ± 0.016^{ab}	0.643 ± 0.006^{a}
	I2	0.456 ± 0.021^{f}	0.493 ± 0.006^{ef}	0.533 ± 0.033^{c-f}	0.550 ± 0.017^{b-e}
	I3	0.483 ± 0.016^{ef}	0.483 ± 0.016^{ef}	0.513 ± 0.008^{def}	0.543 ± 0.012^{cde}
TSS/TA	I1	29.59 ± 0.948^{d-g}	27.44 ± 0.030^{fg}	26.35 ± 0.826^{fg}	25.54 ± 0.095^{g}
	I2	41.22 ± 2.141^{a}	37.45 ± 0.660^{bcd}	34.38 ± 2.132^{bcd}	32.06 ± 1.015^{c-f}
	I3	38.33 ± 0.881^{ab}	38.40 ± 1.928^{abc}	36.90 ± 0.750^{abc}	32.53 ± 0.566^{b-e}

*Different letters represent significant differences by Tukey's honesty test ($p \leq 0.05$). Each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

revealed that increasing cluster weight generally paralleled with the increase of irrigation levels. Besides, the highest significant values were found in the treatment of SAP at 900 g under 100% and 80% ETc in both seasons, while the lowest average of cluster weight was recorded with the 60% ETc irrigation without SAP amendment in both seasons.

According to the findings in the same table, raising the SAP application doses from 300 to 900 g enhanced the yield/vine (kg/vine), and yield (kg /fed.) compared to the control. Data presented also, that 80% ETc recorded the highest values compared to 60% and 100% ETc with the application of SAP doses in both seasons. Moreover, when comparing the treatment of SAP at 900 g at 80% ETc to the control, the highest significant values were discovered. On the contrary, the lowest yield was recorded with 60% ETc irrigation without SAP amendment in both seasons.

Water use efficiency as the ratio between the yield and irrigation water amount was calculated and presented in Table 11. It appeared that the increase of SAP dose from 300 up to 900 g in the soil improved WUE in both seasons. The data presented also show that 80% of ETc recorded the highest values compared to 60% and 100%

TABLE 11. Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on cluster characteristics, yield, and WUE of 'Early Sweet' grapevines.

Treatments	SAP1	SAP2	SAP3	SAP4	(control)
2020					
Cluster No.	I1	22.66 ± 0.333^{bc}	22.33 ± 0.333^{bcd}	21.33 ± 0.333^{cde}	20.00 ± 0.333^{def}
	I2	26.66 ± 0.666^{a}	23.66 ± 0.333^{b}	21.66 ± 0.333^{cde}	20.66 ± 0.000^{efg}
	I3	19.33 ± 0.666^{fg}	18.33 ± 0.333^{gh}	17.33 ± 0.333^{h}	17.00 ± 0.000^{h}
Cluster weight (g)	I1	645.0 ± 2.886^{a}	625.0 ± 1.154^{abc}	$605.0 \pm 2.886^{b-e}$	585.0 ± 5.859^{def}
	I2	633.3 ± 3.333^{ab}	618.0 ± 1.527^{abc}	601.3 ± 6.641^{cde}	578.0 ± 9.291^{ef}
	I3	608.0 ± 2.645^{bcd}	569.0 ± 7.234^{fg}	548.0 ± 6.027^{gh}	529.0 ± 8.962^{h}
Yield/vine (kg/ vine)	I1	14.56 ± 0.185^{b}	13.86 ± 0.272^{bc}	13.06 ± 0.202^{cd}	12.10 ± 0.288^{de}
	I2	16.86 ± 0.371^{a}	$14. 60 \pm 0.251^{b}$	12.76 ± 0.32^{cde}	11.56 ± 0.202^{ef}
	I3	11.66 ± 0.433^{ef}	10.40 ± 0.115^{fg}	9.50 ± 0.300^{gh}	8.93 ± 0.145^{h}
Yield/Fed. (kg /fed.)	I1	10196.6 ± 129.9^{b}	9706.6 ± 190.9^{bc}	9146.6 ± 141.9^{cd}	8470.0 ± 202.0^{de}
	I2	11806.6 ± 259.8^{a}	10220.0 ± 176.1^{b}	8936.6 ± 229.8^{cde}	8096.6 ± 141.9^{ef}
	I3	8166.6 ± 303.3^{ef}	7256.6 ± 61.73^{fg}	6650.0 ± 210.0^{gh}	6253.3 ± 101.7^{h}
WUE	I1	2.66 ± 0.033^{ef}	2.54 ± 0.051^{fg}	2.39 ± 0.037^{fg}	2.21 ± 0.054^{g}
	I2	3.86 ± 0.084^{a}	3.34 ± 0.056^{bc}	2.92 ± 0.075^{de}	2.72 ± 0.046^{ef}
	I3	3.55 ± 0.133^{ab}	3.16 ± 0.026^{cd}	2.90 ± 0.090^{de}	2.64 ± 0.046^{ef}
2021					
Cluster No.	I1	20.66 ± 0.333^{bc}	20.33 ± 0.333^{bc}	19.00 ± 0.000^{cd}	18.66 ± 0.333^{cde}
	I2	26.66 ± 0.333^{a}	22.66 ± 0.333^{b}	20.33 ± 0.333^{bc}	18.66 ± 0.666^{cde}
	I3	17.66 ± 0.666^{de}	17.33 ± 0.333^{de}	16.66 ± 0.881^{de}	16.33 ± 0.333^{e}
Cluster weight (g)	I1	656.0 ± 21.07^{a}	636.0 ± 7.549^{ab}	616.0 ± 11.846^{abc}	$596.3 \pm 16.148^{a-d}$
	I2	645.0 ± 7.637^{ab}	630.0 ± 8.082^{ab}	613.6 ± 08.647^{abc}	589.3 ± 9.614^{bcd}
	I3	$596.0 \pm 14.571^{a-d}$	580.3 ± 21.403^{bcd}	559.3 ± 08.511^{cd}	540.0 ± 7.211^{d}
Yield/vine (kg/ vine)	I1	13.60 ± 0.650^{bc}	12.90 ± 0.152^{bcd}	11.70 ± 0.230^{cde}	11.13 ± 0.433^{def}
	I2	17.20 ± 0.200^{a}	14.23 ± 0.296^{b}	12.46 ± 0.033^{bcd}	11.03 ± 0.584^{def}
	I3	10.46 ± 0.352^{efg}	10.00 ± 0.288^{efg}	9.33 ± 0.606^{fg}	8.76 ± 0.145^{g}
Yield/Fed. (kg /fed.)	I1	9520.0 ± 455.4^{ab}	9030.0 ± 106.9^{ab}	8190.0 ± 161.6^{ab}	7793.3 ± 303.3^{ab}
	I2	12040.0 ± 140.0^{a}	9513.4 ± 325.2^{ab}	8726.6 ± 23.33^{ab}	7723.3 ± 408.8^{ab}
	I3	7326.6 ± 246.9^{ab}	7000.0 ± 202.0^{b}	6533.3 ± 424.5^{b}	6136.6 ± 101.7^{b}
WUE	I1	$2.64 \pm 0.125^{d-g}$	2.50 ± 0.030^{efg}	2.16 ± 0.083^{g}	2.16 ± 0.083^{g}
	I2	4.17 ± 0.050^{a}	3.45 ± 0.071^{b}	2.88 ± 0.046^{cde}	2.67 ± 0.141^{def}
	I3	3.38 ± 0.114^{b}	3.23 ± 0.095^{bc}	2.67 ± 0.141^{def}	2.83 ± 0.046^{cde}

*Different letters represent significant differences by Tukey's honestly test ($p \leq 0.05$) each season was analyzed separately. SAP1: 900, SAP2: 600, SAP3: 300, and SAP4: 0 g / vine/season. I1: 100% ETc, I2: 80% ETc and I3: 60% ETc.

ETc with the application of SAP doses in both seasons. Moreover, the treatment of SAP at 900 g under 80% of ETc provided the highest significant increase in WUE compared to the control which gave the lowest values in both seasons.

Multivariate analysis of the parameters

Principal component analysis (PCA) (Fig. 1) was used to examine relationships between the parameters throughout the two growing seasons (2020 and 2021) on 'Early Sweet' grapevines. The PC1 described 44.6% of the data's variability, while the PC2 did so for 23.9%. The present results in Figure 1 show the strong positive correlations between increasing in average berry weight (g), size (cm^3), average number of clusters/vine and average cluster weight (g) and increasing in yield/vine (kg/vine), and yield/fed (kg /fed.) with using SAP 1 and 2. To generate a correlation matrix, mean values were employed. From this matrix, standard principal component (PC) scores were extracted, and the PCs with values larger than 1.00 were chosen. There were calculated correlations between the original traits and the corresponding PCs. According to PC1 and PC2, a scatter plot was created to show the relationship between accessions in terms of characteristics.

Discussion

Effect of superabsorbent polymer (SAP) doses on soil hydraulic properties

Soil hydraulic properties, specifically the water-holding capacity of soils, play a key role in the ability of soils to sustain plant growth. Since SAP have a high capacity to absorb water and vary in volume throughout wetting and drying cycles, they have the ability to alter the fundamental physical properties of soil, as it works like a sub-miniature reservoir to retain and supply moisture to crops over time **(**Zhan et al., 2004) also SAP is considered as hydrophilic network absorbing a

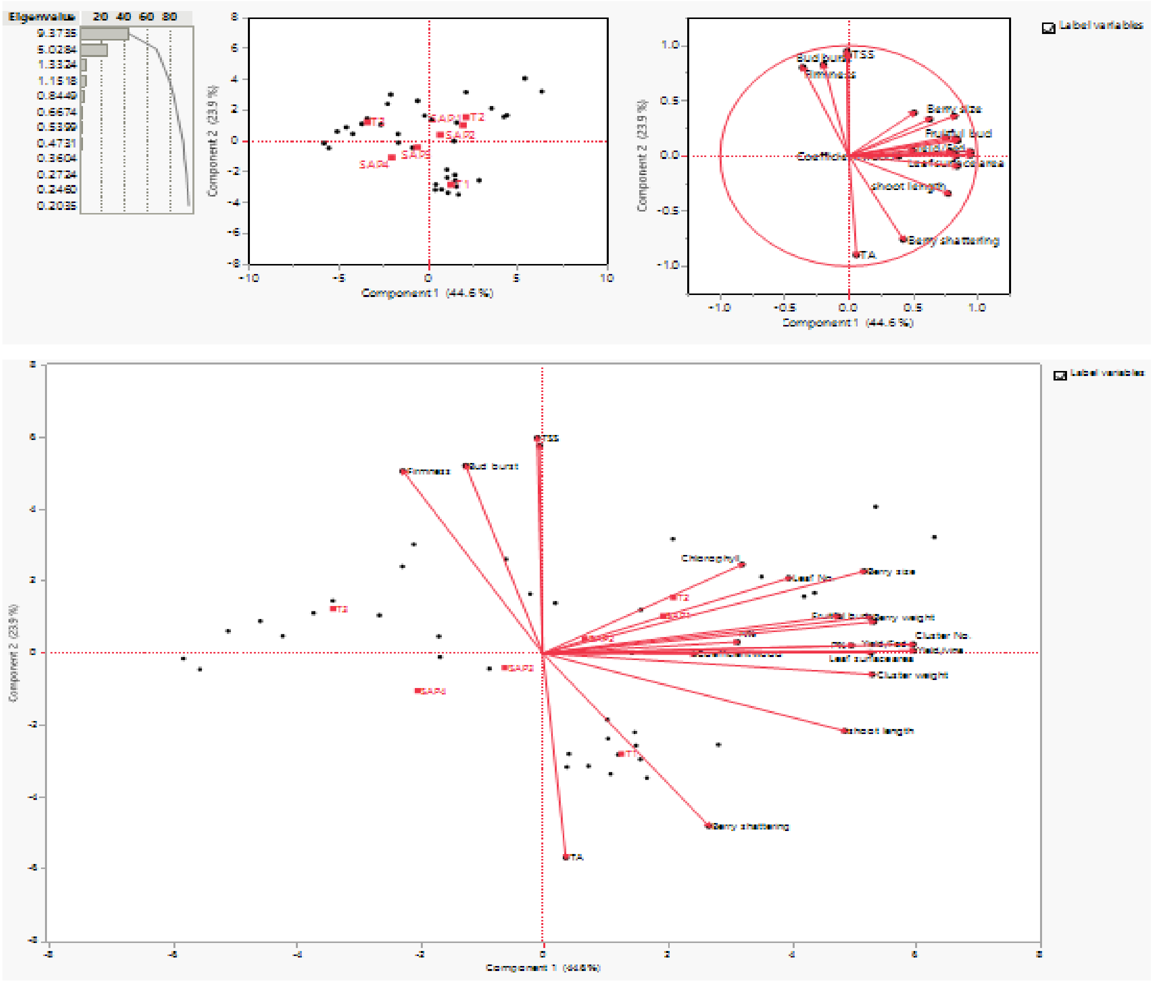

Fig. 1. Principal Components: on Correlations: The correlations are estimated by Row-wise method.

large volume of water (Zohurian-Mehr & Kabiri, 2008) and decreasing water evaporation rate in the soil. This information was confirmed by Zahra et al. (2011), who reported that adding SAP to sandy soil increases the capacity of water storage in soil. As a result, the soil bulk density is reduced and total porosity is increased and it would become more porous than its aeration, and water permeability would be significantly improved (Abdallah, 2019). Our results are consistent with Wu et al. (2008) who studied the relationship between applying SAP and the plant-available water and showed that using these polymers, maintained 10.68% higher water remained in the soil as compared with the control. Nazarli et al. (2010) showed that SAP led to a water retention increase in the soil, reducing irrigation to 50%. Also, soil moisture can be increased by 6.2–32.8% with SAP application (Bai et al., 2010). It was also noted by Pattanaaik et al (2015) that the application of SAP increased the water holding capacity of the soil from 28.74 to 34.63%.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on bud behavior of 'Early Sweet' grapevines

The highest percentage of fruitful buds with SAP application may be due to the increasing water-holding capacity of the soil around the roots. These results are in somewhat agreement with those found by EL Gendy (2012) and Gaser et al. (2018), who reported that water stress was effective in inducing early bud break compared to continuously well-watered vines.

Effect of superabsorbent polymer (SAP) under different irrigation level (I) on vegetative growth of 'Early Sweet' grapevines

Physical characteristics

In general, the deficit irrigation strategy has a negative effect on producing vegetative growth by applying less water because it doesn't offer dynamic water implications at different phenological stages. Vegetative growth as expressed by shoot length leaves number/shoot, leaf surface area/vine, and coefficient of wood ripening were negatively affected by reducing irrigation amount. These findings imply that, as seen in earlier studies using various grape cultivars, the water provided increased vine vegetative growth (Intrigliolo & Castel, 2010 and Cabral et al., 2021). The increment in vegetative growth parameters with adding SAP to the soil may be due to its role in increasing organic materials and availability of proper amounts of nutrients in the soil, additionally, SAP can enhance the soil's physical characteristics and water-holding capacity, resulting in better irrigation water conservation and preventing moisture stresses that have an adverse effect on vegetative growth (Sheikh Moradi et al., 2010). The increase in leaf area might be due to the SAP's ability to hold water, which improves shoot and leaf growth and creates large canopy volumes as compared to control (Austin & Bondari, 1992). This is confirmed by Branch et al. (2009), who showed that the application of SAP increases vegetative growth by increasing the soil's capacity to store water and nutrients. This result agreed with Gaser et al. (2018), who reported that water stress decreased vegetative growth traits in grapevine. Additionally, the findings of our study are consistent with those of Pattanaaik et al. (2015), who discovered that soil application of SAP at a concentration of 100 g/tree greatly improved the vegetative growth of Khasi mandarin compared to the control. According to Abobatta & Khalifa (2019) and Abdel-Aziz et al. (2020), applying SAP considerably boosted growth parameters for Washington Navel orange and Murcott mandarin compared to control. According to these studies, SAP can boost vegetative growth by preventing water and nutrient components from washing away.

It was evident that deficit irrigation, which involves low to moderate water availability, generally results in the maintenance of Calvin Cycle enzyme activity and the maximum rates of carboxylation (*V*cmax) and electron transport (*J*max). (de Souza et al., 2005). However, Antolin et al. (1995) and Manivannan et al. (2007) reported that dehydration stress increased the oxidative process caused by active oxygen species, which disturbs chloroplast structure and causes a reduction in photosynthesis and reduction of chlorophyll content. Drought stress inhibits the photosynthesis of plants by causing changes in chlorophyll content, affecting chlorophyll components, and damaging the photosynthetic apparatus (Iturbe-Ormaetxe et al., 1998). Drought stress caused a significant reduction in Chl a, Chl b, and total chlorophyll content in sunflower genotypes (Manivannan et al., 2007). By lowering the leaf surface temperature and providing adequate soil moisture, Yang et al. (2020) hypothesized that SAP can extend the time during which maize leaves are appropriate for photosynthesis. Additionally, under conditions of adequate water availability, SAP improved plants' ability to transport nutrients and minimized the harm caused by free radicals brought on by drought stress to chlorophyll and the photosynthesis electron transport system, contributing to the accumulation of chlorophyll (Yazdani et al., 2007 and Islam et al., 2011). High contents of polymer in the presence of water supply, caused the opening of stomata for a long time, and subsequently, good fixation of CO_2 increased the photosynthesis of plants (Khadem et al., 2010).

Leaf mineral constituents

Drought stress leads to weak transfer of mineral nutrients from the soil to the plant which causes a decrease in their concentrations in the plants (Hopkins & Hüner, 1995). SAP plays an important role in increasing mineral nutrient concentrations in the plants especially, under drought stress through; 1) Improving the physical condition of the soil (Andry et al., 2009), minimizing the detrimental effects of drought stress and boosting water absorption and retention during water shortage conditions (Yazdani et al., 2007, Islam et al., 2011 and Yang et al., 2020). 2) Working as slow-release fertilizers (Fidelia & Chris, 2011), this is because they can support irrigation and facilitating nutrient transport resulting in releasing water and nutrients to the plants gradually (Oladosu et al., 2022). 3) Increasing soil aeration leads to better microbial activity, which increases the need for some types of chemical fertilizers (Yousefian et al., 2018). Also, the SAP was claimed to decrease nutrient (NPK) leaching (Abdel-Aziz et al., 2020). According to the previous explanations, it could be concluded that the application of SAP enhances leaf mineral contents because it enables absorbing and retaining a considerable amount of water and nutrients that would be slowly released into tree roots. These outcomes are consistent with reports on citrus trees (Vichiato et al., 2004 and El-Enien & Moursi, 2019) and Egazy olive trees (El-Rhman et al., 2017). Similarly, Mikiciuk et al. (2015) reported that polymer application increased nitrogen and potassium contents in strawberry leaves but did not affect phosphorus contents.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on physical and chemical characteristics of berries of 'Early Sweet' grapevines

Berry physical characteristics

Deficit irrigation can inhibit berry growth (Williams & Baeza, 2007), the reduction of berry cell division (McCarthy et al., 2002), and the reduction of berry weight (Wang et al., 2003) and it can influence the development, metabolism, and final composition of the berry (Chaves et al., 2010). It is believed that variations in water import by the xylem, which may lead to a reduction in mesocarp cell turgor, directly explain how water deficit affects berry growth (Thomas et al., 2006). The 'Murcott' mandarin's physical properties, such as fruit weight, fruit volume, and fruit firmness, were improved by adding different levels of SAP to the soil under different irrigation levels (Abdel-Aziz et al., 2020). Similar results were found by Barakat et al. (2015), who found that adding different amounts of hydrogel under different irrigation rates improved the physical characteristics of the fruit of the 'Grand Nain' banana cultivar relative to the control. The highest values of these physical characteristics were obtained when the hydrogel was added to the soil at 100 or 150 g/plant with varying irrigation levels.

Berry chemical characteristics

A moderate water deficit encourages sugar accumulation either directly through the effect of ABA signalling on fruit ripening or indirectly through the inhibition of lateral shoot growth, which causes the reallocation of carbohydrates to fruits (Coombe, 1988 and Deluc et al., 2007). The end-ripening stage of grape berries from vines that had moderate water deficiencies revealed altered mRNA expression patterns, especially in the cell wall, sugar, and hormone metabolism (Deluc et al., 2007). A significant increase in sugar content was observed in 'Cabernet Sauvignon berries under water deficits (Castellarin et al., 2007). In most cases, no the titratable acidity of changes have been observed in the must from moderately water-stressed vines (Matthews & Anderson, 1989 and Esteban et al., 1999). However, some studies report a reduction of titratable acidity due to deficit irrigation as compared with full irrigation (Shellie, 2006 and dos Santos et al., 2007). The malate/tartrate ratio is low due to malate breakdown in vines with low water status (Matthews & Anderson, 1989). The obtained results are in agreement with Wei et al. (2017), who found that irrigation level treatments significantly improved all fruit chemical quality in both seasons. Similarly, Abdel-Aziz et al (2020) indicated that adding SAP at 750 g/tree that received 75% of (ETc) showed the highest values of total soluble solids and achieved the lowest values of acidity in mandarin fruits when compared with control and other treatments.

Effect of superabsorbent polymer (SAP) under different irrigation levels (I) on clusters characteristics, yield, and water use efficiency of 'Early Sweet' grapevines

Due to poor canopy growth and reduced leaf uptake caused by deficit irrigation, the ability of the vine to ripen the crop may be insufficient, which may compromise fruit quality (Romero et al., 2010). The abscission of flowers and flower buds caused by this physiological mechanism, there may be fewer fruits produced per plant due to the decreased availability of photoassimilates needed for the development of floral organs (Cerasola et al., 2022). This outcome is consistent with research on grapevines conducted by (Cabral et al., 2021 and Caruso et al., 2022). In addition, the increase in cluster weight and yield observed in irrigation treatments can be interpreted in view of the fact that these treatments led to the increase in the photosynthetic rate of leaves and then cluster enhanced (Rabeh et al., 2022). From the previous studies, it has been concluded that adding SAP can enhance the fruit's chemical and physical properties because of the prolonged soil moisture, enhanced microbial activity, and higher nutrient availability (Cerasola et al., 2022).

It is noted that the irrigation at 80% ETc is the exact perfect water amount under the conditions of the study, as the slight deficit irrigation provides the plant with more time and chance to receive the benefits of nutrients and cause a significant yield (Rabeh et al., 2022). The obtained results agreed with those of Bryla et al. (2003) as irrigation Florida prince peach trees with (80% ETc) gave the best yield. Regarding the impact of SAP, it does not directly affect nutrition in raising plant yield; rather, this rise is the result of improving soil physical structure and increased mineral uptake, both of which promote plant growth and hence increase tree productivity. Furthermore, polymers stimulate the formation of new roots, providing higher water and nutrient uptake. As a result, SAP treatments increase fruit yield as well as growth and development in plants (Cerasola et al., 2022).

In comparison to well-watered conditions, vines under slight deficit irrigation typically utilize water more efficiently. Lower water use and increased WUE by the crop are evidence of this, which is a key goal of deficit irrigation systems in vineyards (de Souza et al., 2005). This result agreed with Wei et al. (2017) and Gaser et al. (2018) who showed that water use efficiency (WUE) was significantly affected by slight deficit irrigation. Water use efficiency (WUE) can be increased by using SAP under slight deficit irrigation (Rabeh et al., 2022). Improvements in WUE under SAP treatments may be attributed to maintaining enough water available for trees to recover from drought stress injuries, controlling soil water content by increasing its water-holding capacity, reducing deep percolation and evaporation losses in sandy soils, and capturing water that leached from the root zone (Oladosu et al., 2022). Since SAP can effectively boost water efficiency and water use efficiency by increasing the quantity of water-stable aggregates and preventing water evaporation from the soil (Zhao et al., 2019), it shows a significant improvement in sandy soil and arid locations (Bai et al., 2010). Our results are in agreement with (Rabeh et al., 2022) who found that SAP significantly increased the water use efficiency of (Flame Seedless) grapevines grown in sandy soil under a drip irrigation system.

Conclusion

Newly reclaimed sandy soil is considered a promising area if put under proper attention and amended with special irrigation requirements. From the obtained results, it could be concluded that adding a high dose of superabsorbent polymer (900g SAP/vine/season) to 'Early Sweet' grapevine soil was superior in improving soil hydraulic properties (field capacity, welting point, and available water), which made it possible to reduce irrigation rates. Using 900g SAP/vine/season under 80% ETc gave the highest values of vegetative growth, had a positive effect in increasing the quality of berries and clusters, and gave the highest yield as well as water use efficiency. So, regarding the target of limiting of water resources, SAP could be a useful strategy for agricultural sustainability under drought stress for the 'Early Sweet' grapevine.

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Conflicts of Interest

All authors confirm that they have no conflict of interest.

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تأثير تطبيق البوليمر فائق الامتصاص على الخصائص الهيدروليكية للتربة، والنمو ، والإنتاجية ، وكفاءة استخدام المياه لصنف العنب "الأيرلى سويت" تحت مستويات الري المختلفة

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[٢] قسم بحوث المقننات المائية و الرى الحقلى - معهد بحوث الأراضى والمياه والبيئة - مركز البحوث الزراعية الجيزة - مصر.

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تم إجراء هذه الدراسة على مدى موسمين متتاليين (٢٠٢٠ و ٢٠٢١) في مزرعة عنب خاصة تقع في منطقة السادات بمحافظة المنوفية بمصر على صنف عنب ايرلى سويت. تم إجراء تجربتين ميدانيتين، الأولى لتقييم تأثير محسن التربة البوليمر فائق الامتصاص فى شكل مسحوق (SAP) على الخصائص الهيدروليكية للتربة (السعة الحقلية، نقطة الذبول، والماء الميسر)، والثانية لتقييم تأثيره على النمو الخضرى، جودة العناقيد، و كذلك على المحصول وكفاءة استخدام المياه لكرمات العنب "الأيرلى سويت" تحت مستويات مختلفة من مياه الري. تمت معاملة التربة بجرعات مختلفة من البوليمر فائق الأمتصاص (٩٠٠ ، ٦٠٠ ، ٣٠٠ ، أو ٠ جم SAP / كرمة / موسم ، ومستويات مختلفة من مياه الري (١٠٠٪ ، ٨٠٪ ، ٦٠٪ ETc). أظهرت نتائج التجربة الأولى تحسنًا في الخواص الهيدروليكية للتربة والتي زادت بزيادة جرعات البوليمر فائق الإمتصاص، والتي يمكن أن تقلل من كمية مياه الري المطلوبة. أظهرت نتائج التجربة الثانية أن نسبة تفتح البراعم تزداد تدريجياً بإنخفاض معدلات مياه الري وزيادة جرعات البوليمر. أما بالنسبة للبراعم الثمرية، فقد سجل ٨٠٪ من ETc أعلى نسبة معنوية باستخدام جرعات ٩٠٠ و ٦٠٠ جم من البوليمر لكل كرمة. علاوة على ذلك ، أعطى إضافة ٩٠٠ جم من البوليمر لكل كرمة تحت مستوى رى ٨٠٪ ETc أعلى قيم لقياسات النمو الخضرى (طول الفرع، عدد الأوراق / الفرع، إجمالي مساحة المسطح الورقى / الكرمة، معامل نضج الخشب، محتوى الكلوروفيل والمكونات المعدنية للأوراق). علاوة على ذلك ، أظهرت النتائج أن الخصائص الفيزيائية والكيميائية للحبات قد زادت بزيادة جرعات البوليمر تحت مستوى رى ٨٠٪ ETc. فيما يتعلق بالمحصول وكفاءة استخدام مياه الرى، أعطت معاملة إضافة ٩٠٠ جم بوليمر لكل كرمة تحت مستوى رى ٨٠٪ ETc أعلى قيم معنوية كذلك اعطت اعلى نسبة توفير لمياه الرى (حوالى ٢٠٪).

الكلمات الدالة: نقص المياه ، البوليمر فائق الامتصاص ، العنب «الأيرلى سويت» ، كفاءة استخدام المياه ، المحصول، الجودة.