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Efficiency of Using Superabsorbent Polymers in Reducing Mineral Fertilizer Rates Applied in Autumn Royal Vineyards

Mervat A. Ali [1], Samir G. Farag [1], Mika Sillanpää [2], Saleh Al-Farraj [3] and Mohamed E. A. El-Sayed [4,*]

[1] Viticulture Research Department, Horticulture Research Institute, Agricultural Research Center, Giza 12112, Egypt
[2] Department of Biological and Chemical Engineering, Aarhus University, Nørrebrogade 44, 8000 Aarhus, Denmark
[3] Department of Zoology, College of Science, King Saud University, Riyadh 11421, Saudi Arabia
[4] Soils, Water and Environment Research Institute, Agriculture Research Center, Giza 12112, Egypt
* Correspondence: eid1592003@yhoo.com or mohamed.elsayed@arc.sci.eg

Abstract: Superabsorbent polymers (SAPs) addition to soil enhances the properties of soil and increase plant yields. Investigation of the efficacy of SAPs to reduce the rate of mineral fertilizers and produce high-quality grapes was the study's main goal. This investigation was carried out for three seasons (2019, 2020, and 2021) in a private vineyard located in El-Menofia Governorate, Egypt. Autumn Royal grapevines were grafted on Freedom. The vines were seven years old and grown in newly reclaimed sandy soil irrigated by drip irrigation. Several concentrations of polyacrylamide polymer (50, 75, and 100 g/vine/three years) were applied to the examined soil with nitrogen and potassium fertilization rates of 100%, 75%, and 50% of the recommended rate of fertilizer. The data revealed that increasing the amount of applied polymer significantly improved bud burst and fruitful buds percentages; growth parameters; total leaf chlorophyll content; N, P, and K percentages in leaves; and yield. Thus, the most effective method for increasing fruit production was to apply 45 units of N and 75 units of K per feddan, along with 70 kg per feddan of soil conditioner, which is safe for humans and improves the physical and chemical properties of the soil. This treatment considers the impact of SAPs on the preservation of nutrients.

Keywords: superabsorbent polymers; mineral fertilizers; vineyards; soil fertility; soil properties

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1. Introduction

Today, the world has shifted towards clean agricultural techniques in order to reduce pollution, by using natural materials such as biological fertilizers instead of conventional fertilizers. This is the current trend towards the use of natural materials in the fertilization process, and it is also considered one of the clean or sustainable farming techniques through which production can be increased in both quality and quantity [1]. Moreover, nitrogen and potassium can affect numerous significant metabolic processes in plants, such as energy transport, photosynthesis, respiration, and the synthesis of carbohydrates [2,3]. Many attempts are being made to detect the opportunity of applying several new natural materials to enhance soil fertility and fruit tree productivity, as well as reducing the extent of pollution accruing in the environment due to the exaggeration in the application of chemicals and minerals [4,5].

Organic and nano-farming are considered new practices in agriculture for the management of production that support the health of the agro-ecosystem, including biological cycles, biodiversity, and soil activity. They have been widely and consistently practiced in underdeveloped nations, including Egypt [6,7].

The unusual reversals and environmental complexities that the agro-agriculture industry has recently faced in the world has led to the emergence of nanotechnology in

agriculture, which is now recognized as a new approach in developing sustainable agricultural practices. Nano-farming has succeeded in raising the growth and development of plants in conjunction with improving the quality of production, as well as genetic progress, plant adaptation to external stress, conservation of vital energy, and other beneficial characteristics [8].

Superabsorbent polymers are substances that have a high water absorption capacity compared to their bulk. SAPs are commonly used substances across various fields due to their nature and attributes. To investigate the usage of SAPs in agricultural and environmental science, a systematic review was undertaken [9].

A promising grapevine cultivar that has grown well in Egypt's climate is Autumn Royal, a medium-late-ripening seedless table grape variety. However, further research is still required to precisely determine how much nitrogen and potassium the vines will require at each stage of their growth and development.

Superabsorbent polymers can be used and added to soil in arid and semiarid regions to increase the efficiency of adding fertilizer. It is assumed that SAPs chelate significant amounts of nutrients that are released according to the plant's requirements. Consequently, plant production can be enhanced. When polymers are incorporated with soil, it is presumed that they retain large quantities of water and nutrients, which are released as required by the plant. The use of an SAP as a carrier and regulator of nutrient release is helpful in reducing undesired fertilizer losses, while sustaining vigorous plant growth [10]. In addition, the application of SAPs is considered a sustainable fertilizer-saving technology in arid and semiarid regions because it reduces fertilizer losses from the soil. Furthermore, agricultural polymers can retain fertilizers for up to five years [11].

The overreaching purpose of this paper is to develop clean agriculture through minimizing the use of synthetic fertilizers so that it is sustainable, by emphasizing the importance of this approach and making suggestions on how to reduce usage of mineral fertilizers through the inclusion of some environmentally safe materials. Thus, the current paper aims to: (i) investigate the possibility of using SAPs in conjunction with different rates of the mineral fertilizers N and K to achieve maximum yield with better bunch quality of Autumn Royal grapevines; and (ii) evaluate the SAPs' effectiveness at lowering the use of N and K mineral fertilizers without compromising yield and soil characteristics.

2. Materials and Methods

Seven-year-old "Autumn Royal" grapevines were used for the experiment at a private vineyard in El-Sadat City, 30°23′12.01″ N and 30°29′43.92″ E, El-Menofia Governorate, Egypt (Figure 1). The experiment was undertaken in two subsequent seasons, 2020 and 2021, including a preliminary season in 2019. Under drip irrigation, the vines were trellised using the Spanish Parron technique and placed 2 × 3 m apart. Pruning was carried out in the third week of January with a bud load of 96 buds per vine (8 shoots × 12 buds each). The preliminary season (2019) was used to overcome the residual effects of the previously used fertilizers, with SAPs added only once during this season because their effect extends into the subsequent years of the study. All vines were subjected to normal horticultural practices. Table 1 displays the properties of the tested soil before initiating the experiment.



Figure 1. Location satellite image.

Table 1. Some of the investigated soil's physical and chemical characterristics.

Soil Characteristics	Value	Soil Characteristics	Value
Particle size distribution%:		Soil chemical properties:	
Sand	85.20	pH (1:2.5) Soil extract susp.	8.1
Silt	8.63	$CaCO_3$%	17.5
Clay	6.17	OM%	0.66
Textural class	Loamy sand	ECe (dS/m)	2.03
Soil physical properties:		Soluble cations and anions (soil paste, meq L^{-1})	
BD (g.cm^{-3})	1.68	Ca^{2+}	8.88
TP (%)	38.00	Mg^{2+}	7.65
FC (%)	12.60	Na^{+}	12.80
WP (%)	4.38	K^{+}	0.91
AW (%)	8.22	HCO_3^{-}	11.80
WHC (%)	28.10	Cl^{-}	14.90
HC (cm/s)	1.9×10^{-3}	SO_4^{2-}	3.60

ECe: electrical conductivity, OM: organic matter, FC: field capacity, WP: wilting point, AW: available water, BD: bulk density, TP: total porosity, HC: hydraulic conductivity (cm s^{-1}), WHC: water holding capacity.

2.1. Design and Procedures Used in the Experiment

Completely randomized block design was used in the experiment; each treatment was replicated three times and each replicate contained five vines.

The experiment involved nine treatments as follow:

(T1) 60 units N + 100 units K/Fed
(T2) 45 units N + 75 units K/Fed
(T3) 45 units N + 75 units K + 35 kg polymer/Fed (50 g/vine)
(T4) 45 units N + 75 units K + 53 kg polymer/Fed (75 g/vine)
(T5) 45 units N + 75 units K + 70 kg polymer/Fed (100 g/vine)
(T6) 30 units N + 50 units K/Fed
(T7) 30 units N + 50 units K + 35 kg polymer/Fed (50 g/vine)
(T8) 30 units N + 50 units K + 53 kg polymer/Fed (75 g/vine)
(T9) 30 units N + 50 units K + 70 kg polymer/Fed (100 g/vine)

Mineral fertilizers (nitrogen as ammonium sulphate (20.6% N) and potassium as potassium sulphate (50 % K_2O)) were used in batches during the growing season: 50% N and 25% K after bud burst and before flowering, 25% N and 50% K after berry set, and 25% N and 25% K after harvest. Hydrogels as SAPs have been widely used in agriculture as soil amendments in developed countries. SAPs are hydrophilic networks capable of absorbing massive amounts of fertilizer [11]. SAPs were applied to the soil at 30 cm depth on both sides of vines under irrigation lines in the first week of February 2019. Soil amendments (SAPs) were obtained from the Agriculture Research Center (ARC), and some chemical analysis was performed to explore the composition (Tables 2 and 3). According to Ahmed (1992) [12], these composites comprise a 1:5 combination of SAPs and clay deposits (bentonite).

Table 2. List of major components of superabsorbent polymers (SAPs) and composites.

Superabsorbent Polymers (SAPs)			Major Components
A		Aqua keep Arasoubu S-107 Aron T-121	Polyacrylic acid Polyacrylic acid Polyacrylic acid
B		Bargas 700	Polyacrylic acid
1		Sanwet H-5000D	Polyacrylic acid
		Composites	
	B1	SAP-20%	Bentonite + SAP-20%
2	K1	A SAP-20%	Kaolinite + SAP-20%
3		B2	-
4		K2	-
5		N15	-
6		N20	-

Table 3. Several features of the studied polymer.

pH	7.12
Bulk density (g/cm^3)	0.67
Real density (g/cm^3)	1.72
Total porosity (%)	61.0
Water holding capacity (WHC) cm^3/g^{-1}	60.0

2.2. Examined Parameters

2.2.1. Bud Behavior Measurements

The bud burst and fruitful buds percentage were determined by the following equation:

$$\textbf{Bud burst } (\%) = (No.\ of\ burst\ buds/No.\ of\ bud\ loads/vine) \times 100$$
$$\textbf{Fruitful buds } (\%) = (No.\ of\ fruitful\ buds/vine/No.\ of\ burst\ buds/vine) \times 100$$

2.2.2. Yield Components

Yield/vine (kg) was determined as cluster number/vine × average weight of cluster (g).

2.2.3. The Features of Berries

Berry weight (g), berry size (cm^3), TSS/acid ratio was computed using the following data: total soluble solids in berry juice (TSS) (%) by hand refractometer, and total titratable acidity as tartaric acid (%) [13]. According to Yilidz and Dikmen [14], the total anthocyanin of the berry skin (mg/100 g fresh weight) was estimated.

2.2.4. Morphological Properties of Vegetative Growth

The following morphological investigations were carried out at the point of growth cessation on four fertile shoots/the considered vines.

a. Average leaf area (cm^2): The leaves were measured with a CI-203-Laser Area-meter, produced by CID, Inc., Vancouver, WA, USA, utilizing the apical fifth and sixth leaves.
b. Number of leaves/shoots
c. Average shoots length (cm).
d. Average shoot diameter (cm).
e. Wood ripening coefficient was taken in mid-October and, referring to Bouard (1966) [15], calculated by dividing the length of the matured portion of the shoot by the entire length of the shoot.

2.2.5. Properties of Leaves and Shoots

a. N, P and K content in the leaf petioles: Vine leaf blades opposite cluster leaves were collected at full bloom and petioles were collected to determine nutrient status. Leaf blades and petioles were separated, rinsed in distilled water, dried at 65 °C for 48 h and ground to pass through a 425 µm sieve. Nitrogen was determined via combustion analysis, and P and K concentrations were measured using inductively coupled plasma-optical emission spectrometry (ICP-OES) after microwave digestion in HNO_3 [16].
b. The total chlorophyll content of leaves was determined in the fifth and seventh leaves, and measured at full bloom using a nondestructive Minolta—SPAD 502 [17].
c. The total carbohydrate (%) content in shoots: shoot samples were collected at winter pruning (through the first week of January) and total carbohydrate content was determined by referring to Smith et al. (1956) [18].

2.2.6. Soil Analysis

During plant harvest, soil samples were taken from all experimental plots and sieved through a 2 mm sieve after being air dried to investigate:

a. Soil chemical analysis:

The pH of soil was estimated in 1:2.5 (soil: water) using a Beckman pH meter; in addition, the electrical conductivity was determined in 1:5 (soil: water extraction) while the available soil NPK was determined as described elsewhere [19]. Soil organic matter was determined by the Walkley–Black procedure using dichromate ($Cr_2O_7^{2-}$) to oxidize SOC, and iron sulfate ($FeSO_4$) to reduce excess $Cr_2O_7^{2-}$ in solution [20].

b. Soil physical analysis.

Soil bulk density was determined by the Black and Hartge formula [21].

$$\textbf{\textit{Bulk Density}}(\textbf{\textit{BD}}) = \frac{\textbf{\textit{Oven dry weight soil}}}{\textbf{\textit{Sample volume}}} \mathbf{g/cm^3}$$

Using a pressure plate apparatus, the soil moisture constants (field capacity, available water, and wilting point) were determined for each treatment [22,23].

2.2.7. Economic Evaluation

Economic evaluation was calculated based on collected data and carried out over two seasons in accordance with the prices found on the local market for all production input and output. The soil amendments were added at cost only in the first season, and they decomposed after two years.

The total cost is the total of all costs.

Total earnings (LE/Fed) = kg/fed × price/kg (LE).

Total profit equals total income less the total costs.

2.2.8. Statistical Analysis

The data were analyzed for significant differences using Statgraphics Centurion statistical software. Analysis of variance (ANOVA 2) and comparison of means by least significant difference test ($p < 0.05$) when the F-ratio was statistically significant ($p < 0.05$), were performed for each parameter studied in order to evaluate the results [24].

3. Results and Discussion

3.1. Plant Behavior

3.1.1. Bud Behavior

The data in Figures 2 and 3 demonstrate that different mineral fertilizers and applied soil conditioner rates in the second and third seasons of this study significantly affected bud behavior expressed as bud burst (%) and fruitful buds (%).

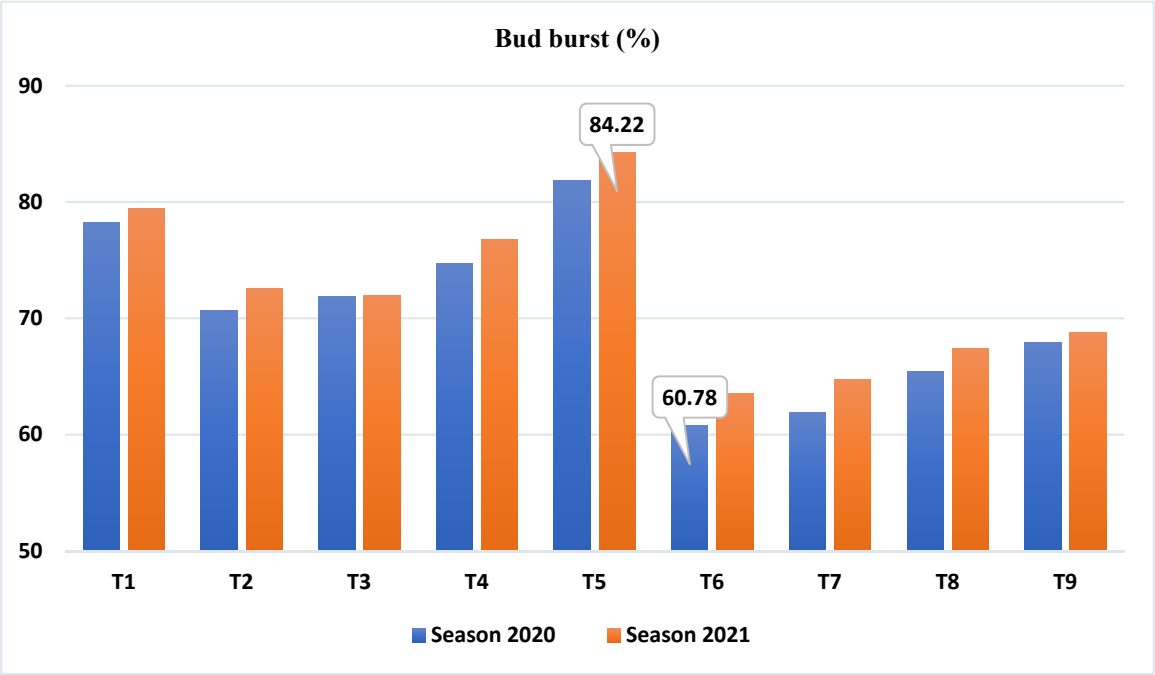


Figure 2. Effect of mineral fertilizer individual or combined with superabsorbent polymers (SAPs) on bud burst (%) of Autumn Royal grapevines in 2020 and 2021 seasons.

Concerning the effect of treatments on bud burst percentage, the data revealed that the treatment 45 units N/Fed. + 75 units K/Fed. + 100 g polymer/vine had the highest significant percentage, while the treatment 30 units N + 50 units K/Fed had the lowest. Moreover, the data showed that the combined application of any dose of mineral N or K with polymer or vine accounted for increased bud burst as compared to the single application. Related to the influence of the treatments on the percentage of fruitful buds per vine, the data in Figures 2 and 3 indicate that the application of polymer combined with mineral N and K resulted in positive effects on the percentage of fruitful buds as compared with the use of mineral N and K alone. The greatest results with regard to this parameter were obtained as a result of fertilizing the vines with 45 units N/Fed, 75 units K/Fed, and 100 g polymer per vine.

The Thompson Seedless fertility coefficient was significantly improved with adequate levels of N fertilizer applied to vines, and the highest fertility coefficient was obtained with a level of N/K vine applied ratio (1N:2K) [25]. In addition, Shafie (2000) [26] explored the influence of SAPs and the increase in fertilizer due to the loss of nutrients from leaching from the soil.

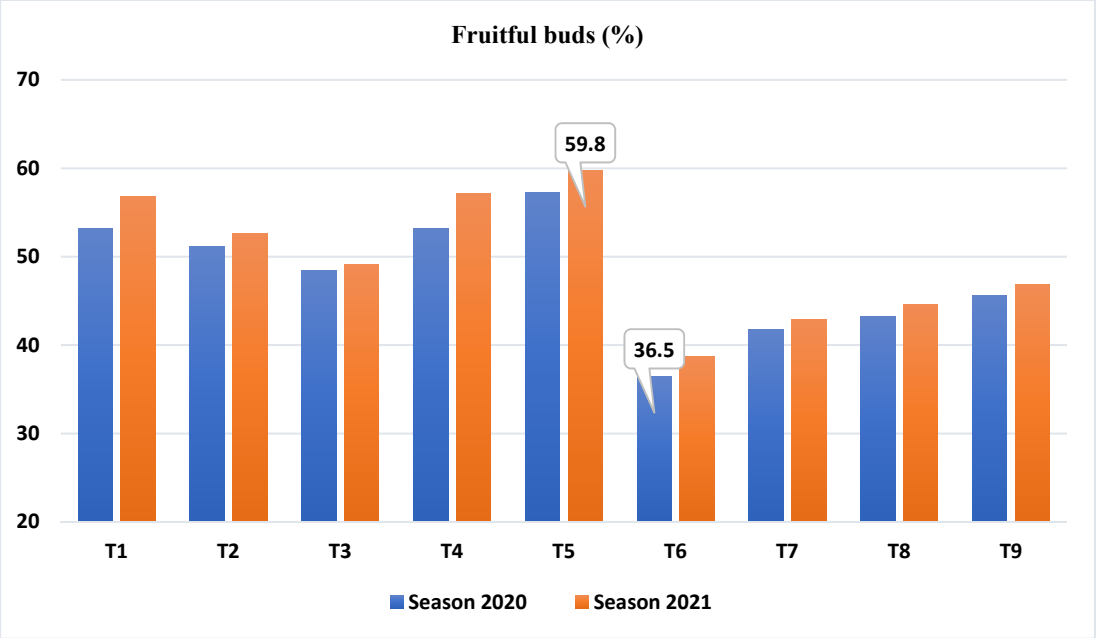


Figure 3. Effect of mineral fertilizer alone or combined with superabsorbent polymers (SAPs) on fruitful buds (%) of Autumn Royal grapevines in 2020 and 2021 seasons.

The progressive effect of SAPs on bud burst and fruitful buds could be attributed to the increased availability of nutrients in the soil. The findings are consistent with those reported by Abd El-Moity et al. (2006) [27], who stated that the bud burst and fruitful buds percentage of Flame Seedless grapevines fertilized with an organic system was higher than that of the mineral source, confirming the findings of this study.

3.1.2. Yield Components

The data in Table 4 reveal that the effects of various tested rates of nitrogen and potassium fertilization as well as the dose of autumn soil amendments had a significant impact on the yield and its contents, including the average weight of clusters and the average number of clusters. The study's second and third seasons of Autumn Royal grapevines showed that vines treated with 100 g of polymer per vine per year produced the highest average of cluster number, average of weight, and yield per vine, while vines that received no polymer and only small amounts of fertilizer produced the lowest average of cluster number, average of weight, and yield per vine.

Table 4. Effect of mineral fertilizer alone or combined with superabsorbent polymer (SAPs) on yield components of Autumn Royal grapevines in 2020 and 2021 seasons.

Treatment	Yield (kg/Vine)		Number of Clusters		Cluster Weight (g)	
	2020	2021	2020	2021	2020	2021
T1	22.11	22.57	35.01	35.21	631.4	640.9
T2	17.12	18.41	29.60	31.13	578.3	591.4
T3	19.24	20.61	32.07	33.44	600.0	616.3
T4	21.46	22.70	34.54	35.75	621.2	634.9
T5	23.81	24.57	36.48	36.91	652.8	665.8
T6	9.70	10.83	19.72	21.89	491.7	494.8
T7	11.39	12.50	22.19	24.20	513.4	516.7
T8	13.19	14.36	24.66	26.51	534.9	541.6
T9	15.10	16.33	27.13	28.82	556.6	566.5
New LSD at 5%	1.63	1.65	0.27	0.29	20.7	21.8

Data analysis revealed that deficits of 75% or 50% of nitrogen and potassium fertilizer requirements significantly reduced yield, cluster weight, and clusters per vine. However, adding soil amendments (SAPs) significantly increased the yield, bunch weight, and number of clusters per vine over the absence of soil amendments, and this increase was generally parallel with the increase in dose of soil amendments. Superabsorbent polymers affect the release of nutrients and soil nitrification, which increases the absorption of nutrients [28].

Osmotic soil moisture and the decrease in transplanting stressors promote plant growth reactions, leading to an increase in yield and a decrease in plant production expenses [29]. The results are matched with those achieved by Farag et al. (2017) [30] on pomegranate and Kassim et al. (2017) [31] on grand nain banana, who both found that high rates of SAP had a positive impact on fruit weight and yield. The available reports concerning the N and P supply on grapevines, yield, weight, and number of clusters matched with results by Abd El-Razek et al. (2011) [32] and Ola et al. (2016) [33].

3.1.3. Physical and Chemical Properties of Berries

As presented in Table 5, the data indicate that physical and chemical properties of berries were significantly affected by different tested rates of nitrogen and potassium fertilization and soil amendment levels (SAPs) of Autumn Royal grapevines in the second and third seasons, such as berry weight, size, total soluble solids (TSS%), acidity, TSS/acid ratio, and anthocyanin content.

Table 5. Effect of mineral fertilizer individual or combined with superabsorbent polymers (SAPs) on physical and chemical characteristics of berries of Autumn Royal grapevines in 2020 and 2021 seasons.

Treatment	Berry Weight (g)		Berry Size (cm^3)		TSS (%)		Acidity (%)		TSS/Acid Ratio		Anthocyanin (mg/100 g FW)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T1	6.57	6.60	6.27	6.30	18.0	18.20	0.53	0.53	33.96	34.34	52.93	54.81
T2	6.44	4.45	6.12	6.14	17.20	17.50	0.59	0.57	29.15	30.70	50.36	53.62
T3	6.47	6.49	6.17	6.18	17.40	17.70	0.57	0.56	30.53	31.61	61.21	61.74
T4	6.51	6.56	6.21	6.23	17.80	17.90	0.56	0.54	31.79	33.15	65.33	66.51
T5	6.65	6.67	6.32	6.35	18.80	19.00	0.48	0.45	39.17	42.22	68.90	70.23
T6	6.24	6.27	5.96	5.98	16.10	16.10	0.68	0.66	23.68	24.39	42.19	42.62
T7	6.30	6.31	6.00	6.07	16.30	16.40	0.65	0.64	25.08	25.63	46.22	47.13
T8	6.33	6.35	6.20	6.23	16.50	16.70	0.63	0.61	26.19	27.38	48.30	49.82
T9	6.39	6.41	6.25	6.26	16.90	17.0	0.61	0.59	27.70	28.81	51.63	53.84
New LSD at 5%	0.02	0.03	0.02	0.03	0.18	0.20	0.01	0.02	1.24	1.23	2.12	2.12

Regarding the impact of nitrogen and potassium fertilization treatments, the results showed that the application of 60 units N per Fed plus 100 units K per Fed was accompanied by considerably enhanced berry quality in turn, by increasing berry weight, size, TSS%, TSS/acid ratio, and anthocyanin, and decreasing total acidity%, in vines receiving 30 units N per Fed plus 50 units K per Fed, which resulted in the lowest value in the second and third seasons. In addition, the results in Table 6 show that the berries' physical and chemical characteristics were significantly different, referring to the addition rate of SAPs and the different tested rates of nitrogen and potassium fertilization treatments in both seasons. In addition, the maximum values of these factors were detected in vines with 100 g of polymer and 45 units N and 75 units K per Fed, while the minimum values of grape parameters were observed with 30 units N and 50 units K per Fed. Regarding nitrogen and potassium supply, similar findings were achieved by Abd El-Razek et al. (2011) [32], who found that berry weight and size were much better when N nutrition was increased.

Table 6. Impact of mineral fertilizer individual or mixed with SAPs on vegetative growth parameters of Autumn Royal grapevines in 2020 and 2021 seasons.

Treatment	Leaf Area cm^2		No. of Leaves/ Shoot		Shoot Length cm		Coefficient of Wood Ripening		Shoot Diameter cm	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T1	212.8	214.5	30.1	31.1	186.7	191.4	1.38	1.43	0.85	0.86
T2	207.5	208.1	28.2	28.4	179.3	180.6	1.28	1.30	0.78	0.79
T3	209.8	210.3	27.5	27.3	173.1	174.3	1.33	1.35	0.80	0.81
T4	211.3	212.8	29.3	31.2	185.4	193.1	1.35	1.38	0.83	0.83
T5	215.7	218.9	30.9	31.4	188.6	196.2	1.43	1.46	0.88	0.91
T6	192.5	194.8	25.8	26.0	160.8	162.1	1.12	1.14	0.75	0.76
T7	196.7	198.3	26.1	26.3	163.2	164.0	1.15	1.16	0.74	0.74
T8	202.5	202.8	26.6	26.8	166.4	167.2	1.18	1.19	0.76	0.77
T9	205.7	206.9	27.0	27.1	168.2	168.9	1.23	1.25	0.77	0.79
New LSD at 5%	1.5	2.4	0.5	0.3	1.8	1.9	0.03	0.03	0.01	0.02

In addition, increasing the K fertilizer application caused a significant increase in the TSS/acid ratio. The beneficial effect of superabsorbent polymers on berry properties may be attributed to its positive action in providing the vines with macronutrient requirements through the growing season and enhancing the soil's chemical and physical properties. Furthermore, enhancing the chemical properties of berries may be attributed to the SAPs' role in creating a good balance between growth and fruiting by nutrient availability in soil (N, P, and K), as revealed by its effect on total carbohydrate increase and resulting in ripening stimulus.

Several investigations in general noted that polyacrylamide enhanced nutritional absorption, which led to improvements [31,34]. The application of 45 units N, 75 units K, and the polymer (SAP) for 100 g/vine per year in both study seasons caused the greatest value of total anthocyanin. These findings concur with those made about pomegranate by Farag et al. (2017) [30], who claimed that plants treated with polymer had considerably increased levels of total anthocyanin.

3.1.4. The Parameters of Vegetative Growth

The data displayed in Table 6 exposed that some morphological properties of the vegetative growth parameters, i.e., average shoot length, number of leaves per shoot, leaf area per shoot, cane thickness, and coefficient of wood ripening, were significantly affected by various examined rates of nitrogen and potassium fertilization and SAPs in Autumn Royal grapevines in the second and third seasons. The obtained data showed that vegetative growth characteristics increased with increasing polymer supply rates of fertilizer and were significantly maximized in response to application of 45 units N/Fed + 75 units K/Fed + 100 g polymer/vine for Autumn Royal grapevines. The minimum values were recorded when vines were not treated with polymer and received 30 units N + 50 units K/Fed. The results were announced during the second and third seasons.

Several studies showed that SAPs improved plant development by increasing the quantity of N, P, and K that was accessible in the soil, particularly with K. Ekebafe et al. (2011) [35] reported that hydrogels are claimed to reduce fertilizer (NPK) leaching. The findings in this regard are consistent with Ayman, 2015 [36], who said that adding hydrophilic polymer to the soil improved the pomegranate leaves' surface area. These outcomes were most likely brought about by the polyacrylamide, which increased holding capacity and decreased sand soil penetration rate. As a result, the soil can store enough fertilizer to support roots and buds [37]. Many investigations have revealed that enhancing soil fertility can encourage vegetative growth [38,39]. According to previous studies, fertilizing encourages vegetative development [40,41]. Excessive fertilization, however, cannot promote development [42] and might possibly be harmful [43].

3.1.5. Leaf Mineral Composition

The leaf N, P, and K content concentrations under various treatments throughout the second and third seasons is shown in Table 7. The data reveal that the maximum significant values of these parameters were gained in vines receiving 45 units N/Fed plus 75 units K/Fed plus 100 g polymer/vine, while vines receiving 30 units N/Fed plus 50 units K/Fed resulted in the lowest value in the second and third seasons.

Table 7. Effect of mineral fertilizer indvidual or combined with SAPs on N, P, and K in leaves of Autumn Royal grapevines in 2020 and 2021 seasons.

Treatment	N%		P%		K%	
	2020	**2021**	**2020**	**2.21**	**2020**	**2021**
T1	2.81	2.87	0.52	0.52	2.78	2.79
T2	2.57	2.59	0.36	0.37	2.54	2.54
T3	2.61	2.63	0.39	0.39	2.6	2.59
T4	2.68	2.69	0.41	0.42	2.63	2.63
T5	2.92	2.94	0.55	0.56	2.88	2.90
T6	2.43	2.45	0.28	0.29	2.32	2.33
T7	2.48	2.48	0.30	0.30	2.35	2.38
T8	2.50	2.51	0.31	0.32	2.42	2.44
T9	2.53	2.53	0.34	0.34	2.45	2.47
New LSD at 5%	0.02	0.02	0.01	0.02	0.02	0.03

The results in Table 7 showed that these parameters increased with increasing the addition rate of applied polymer, owing to the preservation of these nutrients from leaching or loss from the soil. All nutritional elements decreased due to fertilizer reduction but using tested amendments (SAPs) provided nutritional elements within adequate limits. This could be because the SAPs increased the cation exchange capacity. These characteristics prevented cations from being leached by irrigation, as previously discovered by researchers [44–46]. By encouraging the absorption of particular nutrient components, holding them firmly, and delaying their dissolution, SAPs can function as a controlled release mechanism.

As a consequence, the plant may still be able to access the nutrients stored by polymers during the growth phase, leading to increased growth. The greater ability of SAPs to retain nutrients means that these nutrients are released substantially more slowly (mainly N and K). With SAPs that may hold and release in synchronization with plant needs, there seems to be a possibility for boosting plant development and preventing nutrient leaching and loss [47].

3.1.6. Total Chlorophyll in Leaves and Cane Total Carbohydrate Content

The findings displayed in Figures 4 and 5 present the total chlorophyll content in leaves and the cane total carbohydrate content under the tested treatments during the second and the third seasons.

In addition to being a crucial environmental element influencing plant growth, development, and respiration, photosynthesis pigments has unique physiological elements in plants that have an impact on the basal metabolism [48]. Increasing fertilization application rate caused a significant increase in leaf total chlorophyll in the study. The mixture of compound fertilizer and soil conditioner (SAPs) application efficiently reduces the adverse impact of moderate water stress on plant photosynthesis [49]. Similarly, Salah Eldin (2020) [50] found that photosynthesis pigments increase with increasing all doses of soil conditioner in olive plants.

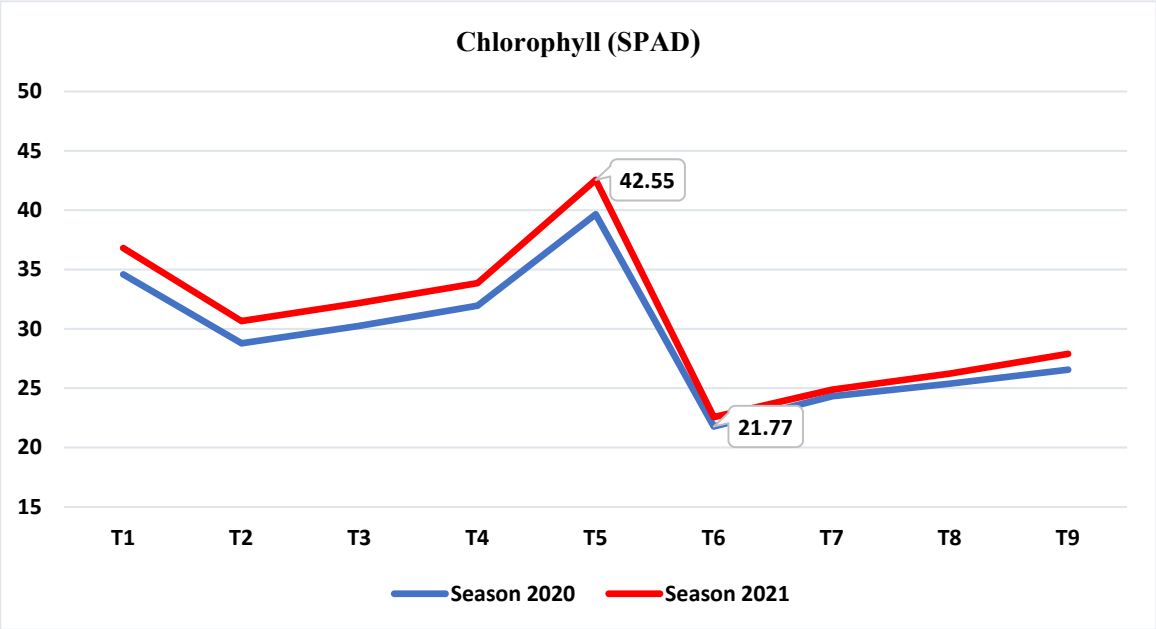


Figure 4. Effect of mineral fertilizer alone or combined with SAPs on total chlorophyll (SPAD) in leaves of Autumn Royal grapevines in 2020 and 2021 seasons.

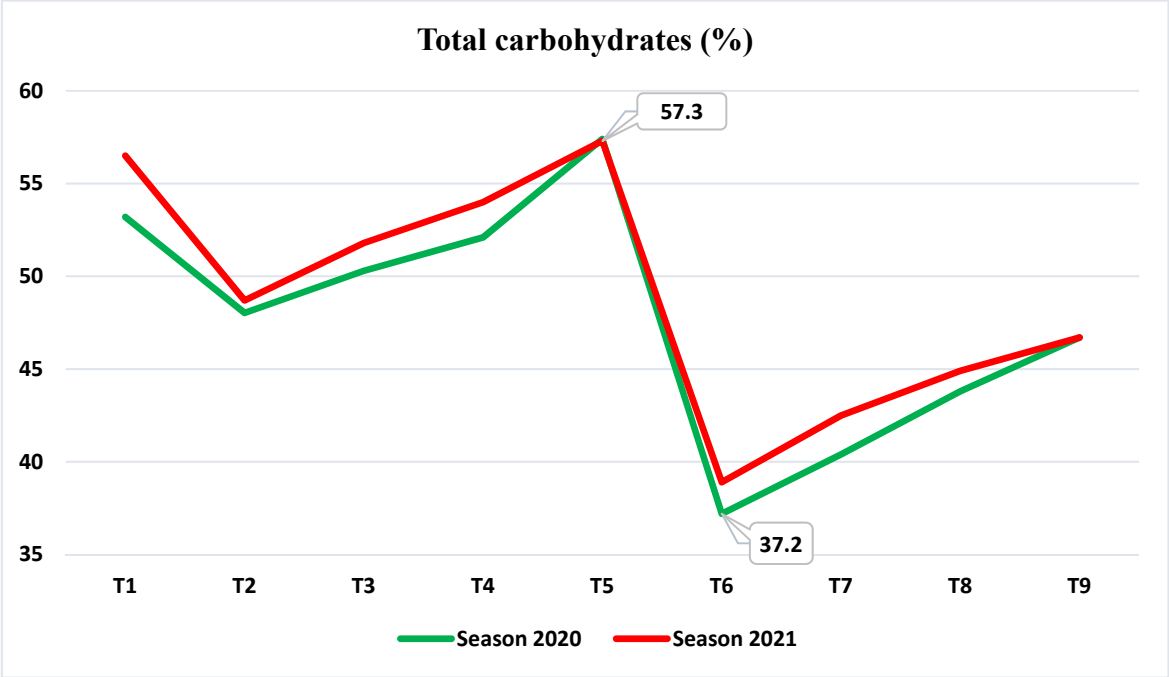


Figure 5. Effect of mineral fertilizer alone or combined with SAPs on shoot total carbohydrate content (%) of Autumn Royal grapevines in 2020 and 2021 seasons.

Regarding the impact of N and P fertilization treatments on the total carbohydrate content of cane, the results indicated that the maximum value was found when vines received 60 units N plus 100 units K per vine, while employing large doses of SAPs increased the value of the total carbohydrate content of cane. The results in this concern are matched with previously published studies that found that SAPs serve several important roles, including supplying the vines with the macronutrients they need throughout the

growing season, moving nutrients, synthesizing and metabolizing plant growth hormones, and storing carbohydrates [32].

3.1.7. Soil Properties

Soil Physical Properties

The information in Table 8 indicates how varying nitrogen and potassium application rates and soil amendment applications affected several physical attributes at the conclusion of the field experiment. Table 8 presents the bulk density (BD) of the soil after the experiment for the two seasons. As a result of applying all the treatments in comparison to the control, BD generally decreased. Results show that the treated fertilizer had a much greater bulk density than the treated fertilizer with the soil conditioner added. Ikpe and Powell (2002) [51] found that increasing the amount of soil amendment supplied resulted in a considerable drop in bulk density values, which enhanced nutrient absorption and increased crop output.

Table 8. Effect of mineral fertilizer alone or combined with superabsorbent polymers (SAPs) on some physical properties of the experimental soil in 2020 and 2021 seasons.

Treatment	Bulk Density (g/cm^3)		HC (cm/s)		FC (%)		WP (%)		AW (%)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T1	1.65	1.67	3.20	3.31	14.2	14.4	4.08	4.09	8.73	8.74
T2	1.54	1.65	3.18	3.26	13.5	13.6	4.03	4.05	8.96	8.98
T3	1.51	1.63	3.24	3.33	13.6	13.8	4.18	4.26	9.61	9.64
T4	1.54	1.66	3.37	3.46	14.6	14.7	4.25	4.31	10.31	10.36
T5	1.55	1.69	3.43	3.51	14.6	14.9	4.37	4.45	10.57	10.59
T6	1.50	1.53	2.87	2.96	12.2	12.5	3.72	3.84	8.48	8.49
T7	1.51	1.55	2.91	3.02	12.5	12.7	3.79	3.96	8.52	8.55
T8	1.54	1.57	2.97	3.03	12.8	12.9	3.87	4.06	8.51	8.63
T9	1.56	1.59	3.11	3.19	13.1	13.3	3.96	3.98	8.68	8.69

According to Dahri et al. (2019) [52], the addition of SAPs in powder and crystal form lowered soil bulk density by 10 and 11.5% and improved soil porosity by 10.20 and 12.60%, respectively. The difference between field capacity, or how much water the soil can store, and wilting point, or when the plant can no longer absorb water from the soil, is known as available water (AW%). As a consequence of adding SAP at a different rate to nitrogen and potassium addition to the soil compared to control throughout the two seasons, the values of field capacity (FC%), wilting point (WP%), and available water (AW%) were all enhanced. With respect to field capacity (FC%), the mentioned data declared that the increase in SAP treatments increased FC% significantly in the two seasons.

Abrishama et al. (2018) [53] demonstrated that increasing SAP addition increased plant-accessible water content significantly. Therefore, with a 143% increase above control, the largest amount of plant-available water was discovered with the SAP (100 g polymer) treatment. This same method also proved the best at keeping soil moisture in place over time. Moreover, Lejcuś et al. (2018) [54] examined the effects of adding SAP to soil on bulk density and water absorption. The findings collected demonstrated the efficiency of SAP treatment for soil water retention (absorption) in contrast to the control sample.

Soil Chemical Properties

Following the harvest of Autumn Royal grapevines over the two investigated seasons of 2020 and 2021, the results presented in Table 9 display various soil chemical features. Findings revealed that, in comparison to the control, the pH of the soil declined as the amount of applied polymer increased in the presence of nitrogen and potassium rates. This pattern persisted for two seasons. These findings support the findings of Dahri et al. (2019) [52], who suggested that the soil's lower pH may have sped up the discharge of

inorganic salts and minerals. As the amount of applied polymer was increased, the electrical conductivity of the tested soil dramatically dropped as a result of the polymer's adsorbed cations, including Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and H^{+}, which decreased the examined soil's ECe value.

Table 9. Effect of mineral fertilizer alone or combined with superabsorbent polymers (SAP_s) on some chemical properties of the experimental soil in 2020 and 2021 seasons.

Treatment	C/N		pH (1:2.5)		ECe (ds/m)		N ppm		K ppm		P ppm		OM%	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T1	1.06	1.08	7.79	8.01	1.69	1.72	91	92	280	276	45	45	1.15	1.13
T2	1.05	1.06	7.88	7.94	1.65	1.66	88	88	260	263	42	43	1.12	1.11
T3	1.18	1.21	7.90	7.98	1.63	1.64	89	91	267	270	45	47	1.23	1.25
T4	1.23	1.27	7.92	8.03	1.58	1.60	91	93	275	278	48	51	1.28	1.29
T5	1.28	1.29	7.96	8.05	1.55	1.58	93	96	300	301	50	54	1.31	1.34
T6	1.00	1.02	7.76	7.83	1.49	1.52	70	71	250	248	30	31	1.04	1.04
T7	1.02	1.03	7.81	7.86	1.46	1.49	72	75	255	251	33	35	1.07	1.09
T8	1.03	1.05	7.84	7.89	1.42	1.44	75	79	262	258	35	38	1.09	1.11
T9	1.10	1.13	7.86	7.91	1.40	1.41	75	82	263	260	38	41	1.11	1.13

In the examined soil, polymer enhanced the quantity of N, P, and K that was readily accessible, particularly K after N. The outcomes support the assertion made by Ekebafe et al. (2011) [33] that hydrogels can decrease fertilizer (NPK) leaching. They stated that the polymer can chelate cations.

The amount of applied polymer increased together with the amount of organic matter (OM) in the investigated soil, which had an impact on soil fertility and the preservation of leachable macronutrients. Moreover, the available N and OM content in the soil, as well as the C/N ratio in the examined soil, were related.

These findings concur with those of Farag et al. (2017) [30], who observed that the application of soil amendment (polymer) was successful in raising the amount of N, P, and K that was readily accessible in the soil. According to Parvathy and Jyothi (2014) [55], SAP may enhance soil characteristics, particularly when moisture availability is restricted. They came to the conclusion that this polymer has good water retention and slow-release qualities, pointing to potential applications in agriculture as they improve fertilizer and efficiency in utilizing water.

Commonly, the highest values of N, P, K, and OM contents in the investigated soil were under the treatment of 45 units N/Fed + 75 units K/Fed+ 100 g polymer per vine. These findings concur with those made by Farag et al. (2017) [30], who observed that adding soil conditioner (polymer) to the soil increased its availability of N, P, and K. The treatment of 45 units N/Fed + 75 units K/Fed + 100 g polymer per vine increased N, P, K, and OM levels in the investigated soil more effectively than other treatments. These findings concur with those made by Farag et al. (2017) [30], who showed that adding soil conditioner (polymer) to the soil increased the amount of accessible N, P, and K.

3.1.8. Economical Evaluation

The data in Table 10 clearly indicated that income from the Autumn Royal grapevine yield from fertilization with 45 units N/Fed + 75 units K/Fed with 100 g SAP where was superior to all treatments in terms of accumulated net income, but a high dose of SAP with the same rate of fertilizer recorded the highest net profit accumulation in the two seasons (2020 and 2021) and was superior to all treatments. Soil amendment was only added in the first season (2019) to all treatments. In this concern, it can be stated that the addition of superabsorbent polymer to mineral fertilizers nitrogen and potassium mitigated the harmful effects and pollution accruing in the environment as a result mineral fertilization. In addition to being secure and non-toxic, polymers help minimize excessive nutrient loss from soil, keeping the agro-ecosystem from becoming contaminated (Islam et al. 2011) [10]. Moreover, SAPs can keep soil wet and fertilizer in place for three to five

years following application, which will improve both the amount and quality of the output (Martin, 1997) [9].

Table 10. Effect of mineral fertilizer alone or combined with superabsorbent polymers on net return of Autumn Royal grapevines in 2020 and 2021 seasons.

Treatment	Total Yield (Ton/Fed)		Gross Income (1000 EGP Fed^{-1})		Fixed Operation (1000 EGP Fed^{-1})		SAP Cost (EGP Fed^{-1})		Fertilizer Cost (1000 LE Fed^{-1})		Total Cost (1000 EGP Fed^{-1})		Average Net Return (1000 EGP Fed^{-1})	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
T1	15.5	15.8	123.8	110.6	22.5	24.1	0	0	4.1	5.0	26.5	29.1	97.2	81.4
T2	12.0	12.9	95.9	90.2	22.5	24.1	0	0	3.0	3.8	25.5	27.9	70.3	62.2
T3	13.5	14.4	107.7	101.0	22.5	24.1	280	0	3.0	3.8	25.7	27.9	81.9	73.0
T4	15.0	15.9	120.2	111.2	22.5	24.1	420	0	3.0	3.8	25.9	27.9	93.2	83.3
T5	16.7	17.9	133.3	120.4	22.5	24.1	560	0	3.0	3.8	26.0	27.9	10.7	92.4
T6	6.8	7.6	54.3	53.1	22.5	24.1	0	0	2.0	2.5	24.4	26.6	29.8	26.4
T7	8.0	8.8	63.8	61.3	22.5	24.1	280	0	2.0	2.5	24.7	26.6	39.0	34.5
T8	9.2	10.1	73.8	70.4	22.5	24.1	420	0	2.0	2.5	24.9	26.6	48.9	43.7
T9	10.6	11.4	84.6	80.0	22.5	24.1	560	0	2.0	2.5	25.0	26.6	59.5	53.3

The price of a kilogram of grapes = **EGP** 8.00 in 2020 season. The price of a kilogram of grapes = **EGP** 7.00 in 2021 season. The price of a kilogram (SAP) = **EGP** 8.00. USD 1.00 = EGP 16.00 approx. Fixed operation cost (EGP Fed^{-1}) pruning, irrigation, pesticides labor, etc.

4. Conclusions

According to the current study, it can be decided that adding superabsorbent polymer led to enhanced soil and vine physical and chemical traits. The positive action of superabsorbent polymer reduced the application rate of mineral N and K fertilization, which alleviated the harmful effects on the environment as well as improving fruit quality and yield.

In general, the treatment of 75% of the fertilizer requirement doses (45 units N + 75 units K)/Fed for Autumn Royal grapevines combined with 70 kg/Fed (100 g/vine) SAPs was superior in enhancing properties of soil and conserving nutrients from leaching out of the soil, and had an impact on vine vegetative growth vigor and yield quality that was confirmed by our economic study. However, more research is needed to determine the efficacy of these substances as well as to find similar substances with higher potency.

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