

Article

Early Sowing Combined with Adequate Potassium and Sulfur Fertilization: Promoting *Beta vulgaris* (L.) Yield, Yield Quality, and K- and S-Use Efficiency in a Dry Saline Environment

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Abstract: Field trials for two seasons (2018/2019 and 2019/2020) were conducted to investigate the influence of the addition of three levels of potassium (K) ($K_1 = 60$, $K_2 = 120$, and $K_3 = 180$ kg K_2O ha⁻¹) and/or sulfur (S) ($S_1 = 175$, $S_2 = 350$, and $S_3 = 525$ kg $CaSO_4$ ha⁻¹) to the soil, as well as the sowing date (the 1st of September, D_1 ; or the 1st of October, D_2) on the potential improvement of physiology, growth, and yield, as well as the quality characteristics of sugar beet yield under soil salinity conditions. With three replicates specified for each treatment, each trial was planned according to a split-split plot in a randomized complete block design. The results revealed that early sowing (D_1) led to significant improvements in all traits of plant physiology and growth, in addition to root, top, and biological yields and their quality, gross and pure sugar, and K- and S-use efficiencies based on root yield (R-KUE and R-SUE). The K_3 level (180 kg K_2O ha⁻¹) positively affected the traits of plant physiology, growth, yield and quality, and R-SUE, and reduced the attributes of impurities, impurity index, and R-KUE. Additionally, the S_3 level (525 kg $CaSO_4$ ha⁻¹) affirmatively affected plant physiology, growth, yield and quality traits, and R-KUE, and decreased impurity traits, impurity index, and R-SUE. The interaction of $D_1 \times K_3 \times S_3$ maximized the yield of roots (104–105 ton ha⁻¹) and pure sugar (21–22 ton ha⁻¹). Path coefficient analysis showed that root yield and pure sugar content had positive direct effects with 0.62 and 0.65, and 0.38 and 0.38 in both studied seasons, respectively, on pure sugar yield. Significant ($p \leq 0.01$) positive correlations were found between pure sugar yield and root yield ($r = 0.966^{**}$ and 0.958^{**}). The study results recommend the use of the integrative $D_1 \times K_3 \times S_3$ treatment for sugar beet to obtain maximum yields and qualities under salt stress (e.g., 8.96 dS m⁻¹) in dry environments.

Keywords: sowing date; potassium use efficiency; sulfur use efficiency; path coefficient; correlations and stepwise regression



Citation: Mekdad, A.A.A.; Rady, M.M.; Ali, E.F.; Hassan, F.A.S. Early Sowing Combined with Adequate Potassium and Sulfur Fertilization: Promoting *Beta vulgaris* (L.) Yield, Yield Quality, and K- and S-Use Efficiency in a Dry Saline Environment. *Agronomy* **2021**, *11*, 806. <https://doi.org/10.3390/agronomy11040806>

Received: 1 March 2021

Accepted: 16 April 2021

Published: 19 April 2021

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1. Introduction

During the period of growth to maturity, plants face many environmental stresses, including salinity, especially in arid and semiarid environments in most parts of the world, including Egypt, where soil salinity increases annually; therefore, these adverse conditions cause a major ecological problem and restrict the performance of plants [1–5]. Salinity is the biggest enemy for plants because, as harmful environmental stress, it causes another harmful stress, “osmotic stress”, which is the lack of water [6,7].

Soil salinity is associated with many factors that destroy the productivity of different crop plants such as low fertility, poor structure, and water restrictions or “osmotic stress” in many parts of the world [8,9]. These destructive factors cause changes in plant metabolism and key physio-biochemical and molecular processes and ultimately reduce

plant growth, then yield, and quality, especially in dry regions. The decrease in crop growth and production due to soil salinity is attributed to ion toxicity, nutritional imbalance, reduced enzymatic and osmotic effects, decreased photosynthetic efficiency, as well as more negative physiological changes [3,4,9,10].

As for sugar production, sugar beet (*Beta vulgaris* L.) is the second source of sugar in many countries of the world, including Egypt. Like many countries around the world, the Egyptian agricultural policy encourages increasing the cultivated areas of sugar beet to increase the production of pure sugar to minimize the gap between sugar consumption and production, as well as meet the requirements of modern established factories. Like other economical crops, sugar beet requires a suitable sowing date and an appropriate integrative fertilization program to become an effective productive crop, especially given the above-mentioned environmental constraints.

Under dry environmental conditions, the proper sowing date of sugar beet plays a vital role in growth, production, physiological, and quality traits. It has been reported that the early sowing of sugar beet causes a marked increase in gross sugar content, and the highest yields of roots and sugars [11–13]. The key environmental variables that define the start of beet growing are temperature, soil moisture, and slight rate of rainfall [14]. As previously mentioned, sowing sugar beet during October markedly increases root weight and yield, total sugar content, and gross sugar yield compared to sowing in November [15]. Another recent study displayed that the early sowing of sugar beet improves quality traits, i.e., sucrose content and quality index. Conversely, the traits of the impurities (e.g., K, Na, and α - amino N) are varied [13].

Beyond the temperature factor (sowing date), some basic factors in salt-affected soils negatively affect the growth and yields of sugar beet such as low soil fertility, the unavailability of key nutrients (e.g., K, S, and Mg), increased Na^+ ion, and limited irrigation water, as well as unbalanced fertilization of N, P, and K [16,17]. To increase crop plant tolerance to soil salinity by mitigating Na^+ and Cl^- damage [18], studies have shown that applying K mitigates the damaging effects of soil salinity on plant growth and productivity [3,19]. It has been confirmed that the enhancing impact of K in increasing sugar beet salt tolerance is achieved through enhancing plant nutritional status and increasing biosynthesis of organic metabolites [20]. As a regulator of plant water content, K is essential for the growth and production of crop plants due to its major role in protein synthesis, osmoregulation, enzyme activation, stomatal movement, photosynthesis, cation-anion homeostasis, and phloem transport [21,22], as well as increasing salinity tolerance in sugar beet [23]. The use of K fertilizer decreases salt stress effects and increases root, top, and sugar yields, pure and gross sugar content, sugar yield, and juice quality characteristics [24–26].

In arid environments, including Egypt, salt-affected soils suffer from high pH and the unavailability of essential nutrients, including K and S, with high contents of Na^+ and Cl^- , as well as low fertility and poor structure [27,28]. For such soils, the application of sulfur (S) may assist in eliminating soil alkalinity during biological S oxidation, and it could enhance crop yield and quality. It is essential for the desired plant growth because it is a component of many key coenzymes and amino acids, such as methionine and cysteine, which are required for the production of structural proteins, and is concerned with the synthesis of chlorophyll, some vitamins, proteins, and carbohydrates [29,30]. Dry environment soils, including Egypt, are becoming deficient in the nutrient S, and thus the use of S as free fertilization is vital to enhance crop yields, including root and sugar yields [31]. S deficiency leads to changes in protein synthesis and may affect the assimilates, thus reducing sugar transformation and storage in sugar beet tubers due to a deficiency in foliar chlorophyll [32]. Application of S at 25 kg ha^{-1} results in a 25% increase in root yield, as well as improved root quality traits through a decrease in α -amino N [33]. Moreover, several positive effects related to sugar beet growth, production, and quality characteristics have been demonstrated [34,35].

However, research work discussing the investigation of potential improvements with early sowing date in combination with K and/or S applied as soil supplementation has

not yet been investigated with sugar beet plants growing in saline soil located in semi-arid environments. Therefore, the current study hypothesized that an early sowing date (the 1st of September compared to the 1st of October) in combination with K (60, 120, or 180 kg $K_2O\ ha^{-1}$) and/or S (175, 350, or 525 kg $CaSO_4\ ha^{-1}$) applied as soil supplementations may mitigate the osmotic stress and ionic imbalance induced by salinity through the positive influences on morpho-physiological traits, yield components, and yield quality, as well as K- and S-use efficiency (based on root yield) in sugar beet grown under soil salinity ($E_{Ce} = 8.96\ dS\ m^{-1}$) conditions over two seasons in an arid environment.

2. Materials and Methods

2.1. Field Trials Details

Two consecutive field experiments, at two different locations on the same site, were carried out for the 2018/2019 and 2019/2020 winter seasons at an experimental station ($29^{\circ}17' N$, $30^{\circ}53' E$, Southeast Fayoum) located at the Faculty of Agriculture experimental farm, Fayoum University. Each experiment was arranged in a split-split plot (three factors—sowing dates, potassium fertilization, and sulfur fertilization—were applied in main plots, subplots, and sub-subplots, respectively) in a randomized complete block design (RCBD), and each experimental treatment was repeated three times. The size of the basic experimental unit was $10.5\ m^2$, consisting of 5 rows of 3.5 m in length and 60 cm in width (i.e., row spacing).

The experimental region is climatically classified as semi-arid [36] on the aridity scale. Pre-season physicochemical characteristics [37] of the 0–50 cm soil depth from the 2018/19 and 2019/20 seasons are presented in Table 1. The experimental soil samples were classified as sandy loam [38] by the USDA Soil Taxonomy. Soil samples were air-dried and sieved through a 2-mm sieve. Approximately 300 g of soil for E_{Ce} measurement was dried, ground, passed through a 10-mesh screen, and saturated with distilled water for 24 h. The pH values of soil samples were measured in saturated soil-water paste using a Bekman pH meter (model Elico, LI120-UK) [37]. Several milliliters of soil-water paste were extracted through a Whitman No. 1 paper filter in Buchner funnel with a vacuum system. The electrical conductivity ($EC\ 25\ ^{\circ}C$) of the soil-paste extracts was determined using a calibrated, temperature-compensating, digital readout conductivity instrument (model 3200, YSI, Inc., Yellow Springs, OH, USA) [37].

Healthy seeds of sugar beet (var. BTS 301 multigerm, Germany; Moderately Tolerant to Salt) were obtained from the Sugar Crops Research Institute, Egyptian Agricultural Research Center, and the seeds were sown on the 1st of September and October in each of the first and second seasons. After sterilization with 1% (v/v) sodium hypochlorite, 2–4 sugar beet seeds were sown in each hill 20 cm apart. Thirty days after planting (DAS) (4–6 leaf stage), the seedlings were thinned to one per hill to reach approximately $83,000\ plants\ ha^{-1}$.

During seedbed preparation, phosphorus (P) at a rate of $120\ kg\ P_2O_5\ ha^{-1}$ as calcium superphosphate (15.5% P_2O_5) was applied to the soil. Nitrogen (N) was applied at $240\ kg\ N\ ha^{-1}$ as ammonium nitrate (33.5% N) in three equal doses; the first dose was applied directly after thinning, and the second and third doses were added immediately before the second and third irrigation, respectively. To apply K that was chosen as an experimental factor, it was applied at three levels ($K_1 = 60$, $K_2 = 120$, and $K_3 = 180\ kg\ K_2O\ ha^{-1}$) as potassium sulfate (48% K_2O). To equalize S amount for all treatments related to K treatments, elemental S was used for this purpose, as well as regarding the S treatments using $CaSO_4$. The K levels were arranged in subplots, and each K level was divided into two equal doses—the first dose was applied upon sowing and the second dose after thinning. To apply sulfur (S) that was chosen as another experimental factor, it was applied at three levels ($S_1 = 175$, $S_2 = 350$, and $S_3 = 525\ kg\ CaSO_4\ ha^{-1}$) as calcium polysulfide ($CaSO_4$, 30% S). The S levels were arranged in sub-sub plots, and each S level was divided into two equal doses applied at 45 and 70 DAS. Thus, nine treatments were maintained (i.e., K_1S_1 , K_1S_2 , K_1S_3 , K_2S_1 , K_2S_2 , K_2S_3 , K_3S_1 , K_3S_2 , K_3S_3) on two sowing dates (early and late sowing) in two years.

Table 1. Pre-season physicochemical characteristics of the tested soil (0–50 cm depth) for the 2018/19 and 2019/20 seasons.

Characteristics	2018/19	2019/20
Particle size analysis		
Sand (%)	73.10	81.98
Silt (%)	13.47	9.07
Clay (%)	13.43	8.95
Soil textural class	Sandy loam	
Physical and chemical analysis		
pH *	7.55	8.35
ECe ** (dS m ⁻¹)	8.56	9.36
CaCO ₃ (%)	7.83	8.03
Organic matter (%)	1.11	0.85
Soluble cations ** (mmolc L ⁻¹)		
Ca ²⁺	22.84	20.80
K ⁺	7.594	3.594
Soluble anions ** (mmolc L ⁻¹)		
HCO ₃ ⁻	8.416	10.416
SO ₄ ²⁻	22.11	24.01
Available nutrients (mg kg ⁻¹ soil)		
Nitrogen (N)	0.07	0.01
Phosphorus (P)	3.84	3.24
Potassium (K)	42.2	36.0
Zinc (Zn)	1.80	1.30
Manganese (Mn)	5.91	3.91
Iron (Fe)	0.88	0.56
Boron (B)	0.46	0.20

* Suspension of soil: H₂O (1:1, w/v) and ** Soil paste extract 1:2.5 soil: H₂O (w/v) for soil characteristics.

2.2. Environmental Growing Conditions

Table 2 shows the values of thermal units during the trial period in two growing seasons (obtained from the Fayoum meteorological station). The number of days was computed from the date of sowing to the date of harvest. Growing degree days (GDD) were computed by total daily mean values of temperatures minus the temperature base value of 3 °C [39]. GDD values were computed for sugar beet using the following equation:

$$\text{GDD} = [(\text{Maximum temperature} + \text{Minimum temperature}) \div 2] - \text{Temperature base (3 °C)}$$

Table 2. The values of thermal units during the trial period in two growing seasons (obtained from the Fayoum meteorological station).

Thermal Units					
Month	2018/2019		Month	2019/2020	
	Early	Late		Early	Late
September, 2018	755.3	—	September, 2019	750.8	-
October, 2018	670.1	670.1	October, 2019	701.1	701.1
November, 2018	503.0	503.0	November, 2019	548.8	548.8
December, 2018	349.2	349.2	December, 2019	361.1	361.1
January, 2019	276.4	276.4	January, 2020	278.7	278.7
February, 2019	305.9	305.9	February, 2020	314.2	314.2
March, 2019	414.5	414.5	March, 2020	438.2	438.2
April, 2019	—	528.5	April, 2020	—	533.6
Total	3274.3	3047.5		3392.8	3175.6

All other cultural practices for the cultivation of sugar beet such as weed control and irrigation were carried out as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

2.3. Sampling

For all determinations, sampling was done twice from all sub-sub plots in the two seasons. At 90 days after sowing (DAS), the first sample was taken to assess vegetative growth traits according to the sowing date. The sample was composed of five fully-expanded upper leaves taken from four sugar beet plants randomly selected to measure both the chlorophyll concentration (SPAD values) and the chlorophyll fluorescence (Fv/Fm) as physiological parameters. The second sample was taken at 210 DAS (harvest stage) from all sub-sub plots in both seasons to evaluate the yield and quality traits according to the sowing date. Each sample consisted of six randomly selected plants, which they were completely removed after irrigation of the soil to facilitate obtaining the plant with the whole root. The plants were then cleaned with tap water and separated into roots and tops to estimate their morphological characteristics. Sugar beet plants from all rows were then collected in each sub-sub plot, plus the six previously sampled plants that were all used to measure yield traits.

2.4. Morpho-Physiological and Yield Attributes

At 90 DAS, the selected samples were subjected to measure SPAD values (the chlorophyll concentration) using a chlorophyll meter (SPAD-502, Plus Konica Minolta, Inc., Tokyo, Japan). To obtain accurate SPAD values, each measurement was performed on both the second and third leaves and the mean of the two readings was recorded for each replicate. The Fv/Fm (chlorophyll fluorescence) was recorded by using (Handy PEA, Hansatech Instruments Ltd., Kings Lynn, UK), as described in [40], while the PI (performance index) was measured as described in [41]. At harvest (210 DAS) in both seasons, the sampled plants were separated into roots and tops to estimate the following traits: root length and diameter (cm) were measured using a meter scale, while root fresh weight and top fresh weight (kg plant^{-1}) were measured using a digital balance. Leaf area index (LAI) was measured using the following equation [42]:

$$\text{LAI} = \text{Leaf area per plant (cm}^2\text{)} \div \text{Plant ground area (cm}^2\text{)}$$

where leaf area per plant was measured using a leaf disc method [42], and plant ground area was assessed by multiplying the distance among plants (20 cm) by row width (60 cm).

2.4.1. Juice Quality Traits

Gross sugar content (%) was determined in [43]. Pure sugar content (%) was calculated according to [44]. The content of impurities in terms sodium (Na), potassium (K), and α -amino-N in (meq per 100 g root) were determined by an Automatic Sugar Polarimetric. Loss sugar (%), purity (%), and alkalinity index were calculated by the following equations:

$$\text{Loss sugar (\%)} = \text{gross sugar (\%)} - \text{pure sugar (\%)},$$

$$\text{Purity (\%)} = [\text{Pure sugar (\%)} \div \text{Gross sugar (\%)}] \times 100,$$

$$\text{Alkalinity index} = (\text{K} + \text{Na}) \div \alpha\text{-amino N}$$

Impurity index was computed from Na, K, and α -amino-N values and gross sugar by the following formula (and with absolute values):

$$\text{Impurity index} = (10 \times \alpha\text{-amino N} + 3.5 \times \text{Na} + 2.5 \times \text{K}) \div \text{Gross sugar (\%)}$$

2.4.2. Yield Traits

Sugar beet plants from all rows of each sub-sub-plot were weighed, in addition to weighing six plants that were previously sampled and then converted to root yield (Mg ha^{-1}) and top yield (Mg ha^{-1}), along with biological yield (Mg ha^{-1}), which was computed by adding the root yield to the top yield (Mg ha^{-1}). Gross sugar yield (Mg ha^{-1}) was calculated by multiplying the root yield by the gross sugar (%). Pure sugar yield (Mg ha^{-1}) was computed by multiplying the root yield by the pure sugar (%). Harvest index (HI) was computed as follows:

$$\text{HI} = [\text{Root yield (Mg ha}^{-1})] \div [\text{Root yield (Mg ha}^{-1}) + \text{Top yield (Mg ha}^{-1})]$$

The K-use efficiency was computed based on root yield (R-KUE as kg root per kg K) and the S-use efficiency was also computed based on root yield (R-SUE as kg root per kg S) by dividing the root yield using K and S rates, respectively.

2.5. Statistical Analysis

The data obtained were statistically analyzed by the technique of analysis of variance (ANOVA) for the split-split plot arranged in randomized complete blocks design using MSTAT-C (MI, USA). Fixed factors were sowing dates, potassium, and sulfur fertilization, while replications were the random factor. Duncan's Multiple Range Test was practiced at 5% and 1% levels of probability to test the differences between treatment means. Correlations and regressions were implemented by IBM SSPS Statistical 21st ed.

3. Results

The use of the highest levels of both potassium (K) fertilizer and sulfur (S) fertilizer combined with early sowing on the 1st of September provided temperatures and nutrition suitable for the growth of sugar beet plants to overcome the conditions of salinity in soil located in a semi-arid environment and secure adequate yields of high quality.

3.1. Effect of Sowing Dates on Sugar Beet Physiological, Growth and Yield Traits

The data listed in Tables 3–5 display that sowing sugar beet early (September 1st; D₁) significantly ($p \leq 0.05$) positively affected Fv/Fm (chlorophyll fluorescence) and PI (performance index) in the 2018/2019 season, SPAD (chlorophyll concentration) in the 2019/2020 season, while PI was highly affected ($p \leq 0.01$) in the 2019/2020 season by sowing early (D₁). There are significant ($p \leq 0.05$ and 0.01) variations between the two sowing dates (D₁: September 1st; and D₂: October 1st) for root length and diameter, and root and top fresh weight plant⁻¹ in both seasons (2018/2019 and 2019/2020), along with leaf area index (LAI) in the second (2019/20) season. There are significant ($p \leq 0.05$) variations between the two sowing dates (D) for impurity index, loss sugar (%), and purity (%) in both seasons (2018/2019 and 2019/2020), α -amino N and alkalinity index in the 1st season, and pure sugar (%) in the second season. The data in Tables 5 and 6 reveal that the two sowing dates (D) showed significant ($p \leq 0.01$) variations in yields (e.g., top, biological, gross, and pure sugar) of sugar beet plants in two seasons (2018/2019 and 2019/2020), as well as in root yield, R-KUE, and R-SUE in the second season. Harvest index significantly ($p \leq 0.05$) varied in both seasons, and root yield, R-KUE, and R-SUE significantly ($p \leq 0.05$) varied in the first season. D₁ significantly outperformed late sowing (October 1st; D₂) by 2.44% (in the 2018/2019) for Fv/Fm, 50.84% (in the 2018/2019) and 57.44% (in the 2019/2020) for PI, and 11.47% (in the 2019/2020) for SPAD. Additionally, D₁ significantly outperformed D₂ for root length by 13.99% and 14.70%, root diameter by 16.34% and 14.77%, root fresh weight by 21.75% and 15.36%, and top fresh weight by 15.36%, and 26.92% in the first and second seasons, respectively, along with LAI by 16.96% in the second season. The highest pure sugar content (18.80% in the second season), purity (90.0% and 89.5% in the first and second seasons, respectively), and alkalinity index (4.60 in the first season) were detected with early sown plants (D₁), while the highest

α -amino N (1.64 in the first season), impurity index (1.64 and 1.68 in the first and second seasons, respectively), and loss sugar (2.39% and 2.52% in the first and second seasons, respectively) were detected with late sowing (D_2). Early sowing (D_1) significantly increased root, top, biological, gross, and pure sugar yields, and R-KUE and R-SUE (83.6, 30.0, 113.88, 17.73, 15.99 Mg ha⁻¹, 0.87 kg root per kg K, and 0.28 kg root per kg S, respectively, in the first season, and 82.6, 32.2, 114.84, 17.42, 15.61 Mg ha⁻¹, 1.45 kg root per kg K, and 0.28 kg root per kg S, respectively, in the second season). On the contrary, the lowest values (0.73 and 0.73, respectively) of the harvest index and aforementioned yield traits were produced from late sowing (D_2) in both two seasons.

Table 3. Effect of sowing dates and applications of potassium and sulfur level and their interactions on photosynthetic efficiency (Fv/Fm, PI (%), and SPAD values), root length (cm), root diameter (cm), and root fresh weight (g plant⁻¹) of sugar beet during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions.

Treatments	Fv/Fm		PI (%)		SPAD Values	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	0.84 \pm 0.002a	0.84 \pm 0.003a	8.04 \pm 0.23a	8.25 \pm 0.25a	55.17 \pm 1.17a	56.37 \pm 1.01a
D ₂	0.82 \pm 0.002b	0.83 \pm 0.002a	5.33 \pm 0.17b	5.24 \pm 0.17b	49.93 \pm 0.47a	50.57 \pm 0.55b
<i>p</i> -value	0.038 *	0.127 ^{ns}	0.015 *	0.005 **	0.088 ^{ns}	0.03 *
	Potassium (K) application					
K ₁	0.81 \pm 0.003c	0.82 \pm 0.002b	5.02 \pm 0.47c	4.93 \pm 0.37c	48.31 \pm 1.45c	49.96 \pm 0.88c
K ₂	0.83 \pm 0.002b	0.83 \pm 0.002b	6.59 \pm 0.35b	6.80 \pm 0.42b	52.58 \pm 1.19b	52.77 \pm 0.99b
K ₃	0.85 \pm 0.001a	0.85 \pm 0.003a	8.44 \pm 0.29a	8.50 \pm 0.51a	56.76 \pm 0.84a	57.67 \pm 1.29a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	0.82 \pm 0.003c	0.83 \pm 0.003a	6.08 \pm 0.43c	6.21 \pm 0.50c	49.53 \pm 0.99c	50.78 \pm 1.17c
S ₂	0.83 \pm 0.003b	0.84 \pm 0.004a	6.68 \pm 0.49b	6.69 \pm 0.56b	52.94 \pm 1.38b	52.81 \pm 1.49b
S ₃	0.84 \pm 0.004a	0.84 \pm 0.005a	7.30 \pm 0.54a	7.34 \pm 0.45a	55.17 \pm 1.55a	55.81 \pm 0.91a
<i>p</i> -value	<0.001 **	0.089 ^{ns}	<0.001 **	<0.001 **	<0.001 **	<0.001 **
Treatments	Root Length (cm)		Root Diameter (cm)		Root FW (g plant ⁻¹)	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	32.0 \pm 0.40a	32.7 \pm 0.65a	13.6 \pm 0.15a	14.2 \pm 0.37a	1470 \pm 20.99a	1463 \pm 42.48a
D ₂	28.0 \pm 0.24b	28.5 \pm 0.31b	11.7 \pm 0.19b	12.4 \pm 0.15b	1208 \pm 22.29b	1268 \pm 18.48b
<i>p</i> -value	0.034 *	0.032 *	0.006 **	0.017 *	0.019 *	0.006 **
	Potassium (K) application					
K ₁	27.6 \pm 0.97c	28.4 \pm 0.49c	11.7 \pm 0.59b	12.5 \pm 0.19c	1239 \pm 1.01b	1269 \pm 22.50c
K ₂	29.7 \pm 0.51b	30.2 \pm 0.48b	12.3 \pm 0.27b	12.9 \pm 0.16b	1296 \pm 35.92b	1322 \pm 19.80b
K ₃	32.6 \pm 0.45a	33.3 \pm 0.82a	13.9 \pm 0.25a	14.5 \pm 0.39a	1482 \pm 32.18a	1507 \pm 43.20a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	28.5 \pm 0.56c	29.5 \pm 0.61c	11.6 \pm 0.24c	12.4 \pm 0.28c	1231 \pm 37.48c	1262 \pm 28.19c
S ₂	29.8 \pm 0.68b	30.2 \pm 1.06b	12.5 \pm 0.30b	13.2 \pm 0.47b	1316 \pm 39.52b	1357 \pm 55.33b
S ₃	31.7 \pm 1.01a	32.2 \pm 0.60a	13.9 \pm 0.58a	14.3 \pm 0.26a	1470 \pm 67.04a	1479 \pm 27.04a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **

*, ** indicate the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different. D₁ = sowing at the 1st of September; D₂ = sowing at the 1st of October; K₁ = 60 kg K₂O ha⁻¹; K₂ = 120 kg K₂O ha⁻¹; K₃ = 180 kg K₂O ha⁻¹; S₁ = 175 kg CaSO₄ ha⁻¹; S₂ = 350 kg CaSO₄ ha⁻¹; S₃ = 525 kg CaSO₄ ha⁻¹; and FW = fresh weight.

Table 4. Effect of sowing dates and applications of potassium and sulfur level and their interactions on top fresh weight (kg plant⁻¹), leaf area index (LAI), sucrose (%), Na, K, and α -amino N (meq per 100 g) and impurity index of sugar beet during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions.

Treat	Top FW (kg Plant ⁻¹)		LAI		Gross Sugar (%)		Na ⁺ (meq Per 100 g)	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
Sowing dates (D)								
D ₁	0.99 \pm 0.02a	1.05 \pm 0.05a	5.23 \pm 0.12a	5.31 \pm 0.28a	21.1 \pm 0.16a	21.1 \pm 0.26a	1.55 \pm 0.03a	1.74 \pm 0.05a
D ₂	0.78 \pm 0.01b	0.84 \pm 0.01b	4.57 \pm 0.11a	4.54 \pm 0.14b	20.0 \pm 0.14a	20.2 \pm 0.17a	1.73 \pm 0.04a	2.01 \pm 0.04a
<i>p</i> -value	0.002 **	0.005 **	0.088 ns	0.037 *	0.169 ns	0.055 ns	0.062 ns	0.08 ns
Potassium (K) application								
K ₁	0.78 \pm 0.06c	0.85 \pm 0.02c	4.26 \pm 0.37b	4.45 \pm 0.08b	19.5 \pm 0.26c	19.7 \pm 0.25c	1.89 \pm 0.06a	2.20 \pm 0.03a
K ₂	0.87 \pm 0.03b	0.91 \pm 0.02b	4.58 \pm 0.15b	4.61 \pm 0.17b	20.4 \pm 0.17b	20.4 \pm 0.21b	1.68 \pm 0.04b	1.88 \pm 0.05b
K ₃	1.01 \pm 0.02a	1.07 \pm 0.05a	5.85 \pm 0.13a	5.71 \pm 0.27a	21.8 \pm 0.19a	21.6 \pm 0.29a	1.36 \pm 0.05c	1.55 \pm 0.09c
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
Sulphur (S) application								
S ₁	0.78 \pm 0.02c	0.83 \pm 0.03c	4.18 \pm 0.14c	4.20 \pm 0.19c	20.1 \pm 0.27c	20.1 \pm 0.25c	1.81 \pm 0.06a	2.04 \pm 0.07a
S ₂	0.87 \pm 0.03b	0.93 \pm 0.06b	4.75 \pm 0.22b	4.74 \pm 0.29b	21.0 \pm 0.30a	21.0 \pm 0.36a	1.67 \pm 0.05b	1.89 \pm 0.09b
S ₃	1.01 \pm 0.06a	1.07 \pm 0.02a	5.76 \pm 0.35a	5.83 \pm 0.14a	20.6 \pm 0.30b	20.7 \pm 0.26b	1.45 \pm 0.07c	1.70 \pm 0.07c
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
K ⁺ (meq Per 100 g) α -Amino N (meq Per 100 g) Impurity Index								
2018/2019		2019/2020		2018/2019		2019/2020		
Sowing dates (D)								
D ₁	3.45 \pm 0.12a	3.46 \pm 0.10a	1.18 \pm 0.07b	1.29 \pm 0.05a	1.24 \pm 0.05b	1.33 \pm 0.05b		
D ₂	4.04 \pm 0.15a	4.05 \pm 0.11a	1.64 \pm 0.06a	1.63 \pm 0.06a	1.64 \pm 0.05a	1.68 \pm 0.05a		
<i>p</i> -value	0.065 ns	0.076 ns	0.039 *	0.120 ns	0.003 **	0.011 *		
Potassium (K) application								
K ₁	4.51 \pm 0.12a	4.49 \pm 0.11a	1.80 \pm 0.09a	1.96 \pm 0.07a	1.85 \pm 0.06a	1.96 \pm 0.05a		
K ₂	3.53 \pm 0.15b	3.54 \pm 0.14b	1.35 \pm 0.09b	1.41 \pm 0.06b	1.39 \pm 0.06b	1.45 \pm 0.05b		
K ₃	3.21 \pm 0.16c	3.24 \pm 0.19c	1.07 \pm 0.07c	1.01 \pm 0.11c	1.08 \pm 0.06c	1.10 \pm 0.10c		
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **		
Sulphur (S) application								
S ₁	4.21 \pm 0.16a	4.22 \pm 0.15a	1.57 \pm 0.10a	1.62 \pm 0.09a	1.53 \pm 0.09a	1.66 \pm 0.09a		
S ₂	3.70 \pm 0.20b	3.66 \pm 0.17b	1.41 \pm 0.11b	1.45 \pm 0.12b	1.41 \pm 0.10b	1.46 \pm 0.11b		
S ₃	3.34 \pm 0.16c	3.38 \pm 0.18c	1.24 \pm 0.10c	1.32 \pm 0.10c	1.38 \pm 0.09c	1.39 \pm 0.09c		
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001	<0.001 **		

*, ** indicate the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different. D₁ = sowing at the 1st of September; D₂ = sowing at the 1st of October; K₁ = 60 kg K₂O ha⁻¹; K₂ = 120 kg K₂O ha⁻¹; K₃ = 180 kg K₂O ha⁻¹; S₁ = 175 kg CaSO₄ ha⁻¹; S₂ = 350 kg CaSO₄ ha⁻¹; S₃ = 525 kg CaSO₄ ha⁻¹; and FW = fresh weight.

Table 5. Effect of sowing dates and applications of potassium and sulfur level and their interactions on pure sugar (%), loss sugar (%), purity (%), alkalinity index, and yields of roots and tops (Mg ha^{-1}) of sugar beet during two growing seasons (Mean \pm SE) under soil salinity ($\text{ECe} = 8.96 \text{ dS m}^{-1}$) conditions.

Treatments	Pure Sugar (%)		Loss Sugar (%)		Purity (%)	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	19.0 \pm 0.19a	18.8 \pm 0.25a	2.10 \pm 0.05b	2.20 \pm 0.04b	90.0 \pm 0.28a	89.5 \pm 0.21a
D ₂	17.6 \pm 0.16a	17.6 \pm 0.17b	2.39 \pm 0.05a	2.52 \pm 0.05a	88.0 \pm 0.29b	87.4 \pm 0.26b
<i>p</i> -value	0.111 ^{ns}	0.026 *	0.034 *	0.041 *	0.021 *	0.021 *
	Potassium (K) application					
K ₁	16.9 \pm 0.27c	16.9 \pm 0.24c	2.60 \pm 0.04a	2.77 \pm 0.05a	86.6 \pm 0.22c	85.9 \pm 0.23c
K ₂	18.2 \pm 0.20b	18.1 \pm 0.22b	2.19 \pm 0.05b	2.28 \pm 0.06b	89.3 \pm 0.31b	88.8 \pm 0.33b
K ₃	19.9 \pm 0.21a	19.6 \pm 0.34a	1.95 \pm 0.058c	2.03 \pm 0.10c	91.0 \pm 0.31a	90.6 \pm 0.58a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	17.9 \pm 0.33c	17.9 \pm 0.31c	2.33 \pm 0.07a	2.59 \pm 0.09a	88.6 \pm 0.50b	87.4 \pm 0.53c
S ₂	18.8 \pm 0.38a	18.6 \pm 0.42a	2.24 \pm 0.09b	2.33 \pm 0.09b	89.1 \pm 0.54a	88.8 \pm 0.61b
S ₃	18.3 \pm 0.36b	18.1 \pm 0.30b	2.17 \pm 0.07c	2.16 \pm 0.08c	89.3 \pm 0.50a	89.2 \pm 0.48a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
Treatments	Alkalinity Index		Root Yield (Mg ha^{-1})		Top Yield (Mg ha^{-1})	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	4.60 \pm 0.19a	4.28 \pm 0.16a	83.6 \pm 0.57a	82.6 \pm 1.81a	30.0 \pm 0.48a	32.2 \pm 0.55a
D ₂	3.67 \pm 0.11b	3.85 \pm 0.13a	69.8 \pm 1.05b	67.4 \pm 0.62b	18.9 \pm 0.43b	21.0 \pm 0.52b
<i>p</i> -value	0.018 *	0.54 ^{ns}	0.02 *	<0.001 **	0.004 **	0.001 **
	Potassium (K) application					
K ₁	3.61 \pm 0.35b	3.43 \pm 0.17c	70.2 \pm 2.52c	69.5 \pm 1.62c	22.1 \pm 1.81c	23.6 \pm 1.43c
K ₂	4.08 \pm 0.25b	3.93 \pm 0.16b	76.2 \pm 1.33b	73.8 \pm 1.60b	24.6 \pm 1.45b	26.4 \pm 1.33b
K ₃	4.72 \pm 0.13a	4.82 \pm 0.20a	84.8 \pm 1.81a	81.9 \pm 2.45a	27.2 \pm 1.26a	29.8 \pm 1.50a
<i>p</i> -value	0.011 *	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	3.39 \pm 0.12c	4.06 \pm 0.18a	74.3 \pm 1.79c	71.9 \pm 1.98c	22.6 \pm 1.33c	24.8 \pm 1.48c
S ₂	4.05 \pm 0.22b	4.03 \pm 0.19a	76.4 \pm 2.00b	74.5 \pm 3.12b	24.5 \pm 1.50b	26.5 \pm 1.60b
S ₃	4.98 \pm 0.31a	4.10 \pm 0.17a	80.5 \pm 3.02a	78.8 \pm 1.74a	26.8 \pm 1.74a	28.5 \pm 1.38a
<i>p</i> -value	<0.001 **	0.670 ^{ns}	<0.001 **	<0.001 **	<0.001 **	<0.001 **

*, ** indicate the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and “ns” point to non-significant variation. Means sharing the same letter in each column are not significantly different. D₁ = sowing at the 1st of September; D₂ = sowing at the 1st of October; K₁ = 60 kg K₂O ha⁻¹; K₂ = 120 kg K₂O ha⁻¹; K₃ = 180 kg K₂O ha⁻¹; S₁ = 175 kg CaSO₄ ha⁻¹; S₂ = 350 kg CaSO₄ ha⁻¹; and S₃ = 525 kg CaSO₄ ha⁻¹.

Table 6. Effect of sowing dates and applications of potassium and sulfur level and their interactions on harvest index, biological, gross sugar, and pure sugar yields (Mg ha^{-1}), harvest index, and use efficiency of K and S of sugar beet during two growing seasons (Mean \pm SE) under soil salinity ($\text{ECe} = 8.96 \text{ dS m}^{-1}$) conditions.

Treatments	Biological Yield (Mg ha^{-1})		Harvest Index		Gross Sugar Yield (Mg ha^{-1})	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	113.88 \pm 0.42a	114.84 \pm 0.9a	0.73 \pm 0.01b	0.73 \pm 0.01b	17.73 \pm 0.08a	17.42 \pm 0.25a
D ₂	89.25 \pm 0.50b	88.49 \pm 0.43b	0.79 \pm 0.01a	0.76 \pm 0.01a	14.11 \pm 0.10b	13.61 \pm 0.08b
<i>p</i> -value	0.005 **	<0.001 **	0.039 *	0.028 *	0.006 **	0.005 **
	Potassium (K) application					
K ₁	92.20 \pm 1.78c	93.15 \pm 1.26c	0.76 \pm 0.01a	0.75 \pm 0.01a	13.76 \pm 0.31c	13.69 \pm 0.016c
K ₂	100.72 \pm 1.11b	100.15 \pm 1.20b	0.76 \pm 0.01a	0.74 \pm 0.01a	15.57 \pm 0.15b	15.07 \pm 0.15b
K ₃	111.76 \pm 1.26a	111.65 \pm 1.62a	0.76 \pm 0.01a	0.74 \pm 0.01a	18.52 \pm 0.18a	17.83 \pm 0.30a
<i>p</i> -value	<0.001 **	<0.001 **	0.318 ^{ns}	0.443 ^{ns}	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	96.72 \pm 1.25c	96.75 \pm 1.42c	0.77 \pm 0.01a	0.75 \pm 0.01a	14.95 \pm 0.22c	14.47 \pm 0.23c
S ₂	100.75 \pm 1.41b	100.96 \pm 1.94b	0.76 \pm 0.01b	0.74 \pm 0.01a	16.14 \pm 0.26b	15.64 \pm 0.40b
S ₃	107.24 \pm 1.94a	107.27 \pm 1.28a	0.75 \pm 0.01c	0.75 \pm 0.01a	16.71 \pm 0.37a	16.47 \pm 0.19a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	0.069 ^{ns}	<0.001 **	<0.001 **
Treatments	Pure Sugar Yield (Mg ha^{-1})		R-KUE (kg Root kg K^{-1})		R-SUE (kg Root kg S^{-1})	
	2018/2019	2019/2020	2018/2019	2019/2020	2018/2019	2019/2020
	Sowing dates (D)					
D ₁	15.99 \pm 0.09a	15.61 \pm 0.23a	0.87 \pm 0.06a	1.45 \pm 0.03a	0.28 \pm 0.02a	0.28 \pm 0.02a
D ₂	12.45 \pm 0.10b	11.92 \pm 0.08b	0.73 \pm 0.05b	1.18 \pm 0.01b	0.24 \pm 0.02b	0.23 \pm 0.02b
<i>p</i> -value	0.007 **	0.005 **	0.032 *	0.005 **	0.03 *	<0.001 **
	Potassium (K) application					
K ₁	11.90 \pm 0.26c	11.75 \pm 0.15c	1.23 \pm 0.01a	1.43 \pm 0.04a	0.24 \pm 0.03c	0.24 \pm 0.01c
K ₂	13.90 \pm 0.15b	13.40 \pm 0.15b	0.67 \pm 0.01b	1.29 \pm 0.03b	0.26 \pm 0.03b	0.25 \pm 0.01b
K ₃	16.87 \pm 0.17a	16.16 \pm 0.29a	0.49 \pm 0.03c	1.22 \pm 0.03c	0.28 \pm 0.03a	0.27 \pm 0.03a
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **
	Sulphur (S) application					
S ₁	13.35 \pm 0.22c	12.92 \pm 0.23c	0.77 \pm 0.08c	1.26 \pm 0.03b	0.42 \pm 0.01a	0.40 \pm 0.01a
S ₂	14.45 \pm 0.27b	13.92 \pm 0.38b	0.79 \pm 0.08b	1.30 \pm 0.05a	0.21 \pm 0.01b	0.21 \pm 0.01b
S ₃	14.90 \pm 0.36a	14.47 \pm 0.20a	0.82 \pm 0.08a	1.38 \pm 0.03a	0.15 \pm 0.01c	0.15 \pm 0.01c
<i>p</i> -value	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **	<0.001 **

*, ** indicate the significant variation at ($p \leq 0.05$) and ($p \leq 0.01$), respectively, and "ns" point to non-significant variation. Means sharing the same letter in each column are not significantly different. D₁ = sowing at the 1st of September; D₂ = sowing at the 1st of October; K₁ = 60 kg K₂O ha⁻¹; K₂ = 120 kg K₂O ha⁻¹; K₃ = 180 kg K₂O ha⁻¹; S₁ = 175 kg CaSO₄ ha⁻¹; S₂ = 350 kg CaSO₄ ha⁻¹; and S₃ = 525 kg CaSO₄ ha⁻¹.

3.2. Effect of Potassium Fertilization on Sugar Beet Physiological, Growth and Yield Traits

Potassium (K) levels had significant ($p \leq 0.01$) variations for Fv/Fm, PI, SPAD, root length and diameter, root and top fresh weight plant⁻¹, LAI, and for all juice quality traits (impurity index, loss sugar content, purity percentage, α -amino N, alkalinity index, and pure sugar content) in both seasons under soil salinity conditions ($\text{ECe} = 8.96 \text{ dS m}^{-1}$) as presented in Tables 3–5. The data in Tables 5 and 6 report that K levels had significant ($p \leq 0.01$) positive effects on all yield traits, but had no significant effects on harvest index in both two seasons. The highest K level (K₃ = 180 K₂O ha⁻¹) outperformed the other two K levels (K₁ = 60 K₂O ha⁻¹ and K₂ = 120 K₂O ha⁻¹) and increased Fv/Fm by 4.94% and 2.41% in the first season, and by 3.66% and 2.41% in the second season compared to K₁ and K₂, respectively. K₃ also increased PI by 68.13% and 28.07% in the first season, and by 72.41% and 25.00% in the second season compared to K₁ and K₂, respectively. Furthermore, K₃ increased SPAD values by 17.49% and 7.95% in the first season, and by 15.43% and 9.29% in the second season compared to K₁ and K₂, respectively. The highest K level (K₃ = 180 kg K₂O ha⁻¹) exceeded the other two levels of K (K₁ = 60 kg K₂O ha⁻¹ and

$K_2 = 120 \text{ kg } K_2O \text{ ha}^{-1}$) for the above growth traits. K_3 increased root length by 18.12% and 9.76%, 17.25% and 10.26%; root diameter by 18.80% and 13.01%, 16.00% and 12.40%; root fresh weight by 19.61% and 14.35%, 18.75% and 13.99%; top fresh weight by 29.49% and 16.09%, 25.88% and 17.58%; and LAI by 37.32% and 27.73%, 35.95% and 23.86% compared to K_1 and K_2 , in the first and second seasons, respectively. K_3 increased gross sugar (%) by 11.79% and 9.64%, pure sugar (%) by 17.75% and 15.97%, purity (%) by 5.08% and 5.47%, and alkalinity index by 30.75% and 40.52% in the first and second seasons, respectively, compared to the K_1 level. Conversely, the K_1 level collected the highest Na^+ content (1.89 and 2.20), K^+ content (4.51 and 4.49), α -amino N content (1.80 and 1.96), impurity index (1.85 and 1.96), and loss sugar (2.60% and 2.77%) in the first and second seasons, respectively. Additionally, K_3 significantly exceeded the other two K levels (K_1 and K_2) for all yield traits, except for R-KUE (kg root per kg K), where K_1 was the best level for this trait. K_3 increased root, top, biological, gross sugar, and pure sugar yields, and R-SUE by 20.80% and 17.84%, 23.08% and 26.27%, 21.22% and 19.85%, 34.60% and 30.24%, 41.76% and 37.53%, and 16.67% and 12.50% in the first and second seasons, respectively, compared to the K_1 level. On the other hand, the K_1 level gave the maximum value of R-KUE (1.23 and 1.43 kg root per kg K, respectively) in both seasons.

3.3. Effect of Sulfur Fertilization on Sugar Beet Physiological, Growth and Yield Traits

The data in Tables 3–5 show significant ($p \leq 0.01$) differences among the levels of sulfur (S) for sugar beet plant Fv/Fm in the first season, and PI, SPAD, growth traits (root length and diameter, root and top fresh weight plant^{-1} , and LAI), and juice quality (gross sugar content, impurity index, loss sugar content, purity percentage, Na^+ , K^+ , α -amino N, and pure sugar content) in both seasons, but this was not true for alkalinity index in the 2019/2020 season. The data in Tables 5 and 6 show that the applied level of S_3 resulted in a significant increase in the yields of sugar beet. The responses of these traits to S were gradually increased by increasing the applied S level. The highest S level ($S_3 = 525 \text{ kg } CaSO_4 \text{ ha}^{-1}$) was associated with increases in Fv/Fm of 2.44% in the first season, in PI of 20.07% and 18.20%, in SPAD of 11.39% and 9.91%, in root length of 11.23% and 9.15%, in root diameter of 19.83% and 15.32%, in root fresh weight plant^{-1} of 19.42% and 17.19%, in top fresh weight plant^{-1} of 29.49% and 28.92%, and in LAI of 37.80% and 38.81% in the first and second seasons, respectively, compared with the lowest level ($S_1 = 175 \text{ kg } CaSO_4 \text{ ha}^{-1}$). The S_2 level ($350 \text{ kg } CaSO_4 \text{ ha}^{-1}$) increased gross sugar content by 2.49% and 2.99%, and pure sugar content by 2.23% and 1.18% in the first and second seasons, respectively, compared to the S_1 level ($175 \text{ kg } CaSO_4 \text{ ha}^{-1}$). The S_3 level ($525 \text{ kg } CaSO_4 \text{ ha}^{-1}$) increased purity (%) by 0.79% and 2.06% in both the 2018/19 and 2019/20 seasons, respectively, and alkalinity index by 46.90% in the first season compared to the S_1 level. On the other hand, the S_1 level collected the highest Na^+ content (1.81 and 2.04), K^+ content (4.21 and 4.22), α -amino N content (1.57 and 1.62), impurity index (1.53 and 1.66), and loss sugar (2.33% and 2.59%) in the first and second seasons, respectively. It significantly ($p \leq 0.01$) increased root, top, biological, gross, and pure sugar yields by 8.34% and 9.60%, 18.58% and 14.92%, 10.88% and 10.87%, 11.77% and 13.82%, 11.61% and 12.00%, and 6.49% and 9.52% in the first and second growing seasons, respectively, compared to S_1 . On the other hand, S_3 significantly ($p \leq 0.01$) decreased R-SUE by 64.29% and 62.50% in the first and second seasons, respectively, and harvest index by 2.60% in the first season compared to S_1 .

3.4. Effect of the Different Two-Way Interactions of the Three Factors Studied

For the effect of the different two-way interactions of the three factors studied (Table S1), Fv/Fm (in the first season), PI, and SPAD (in both seasons) were significantly ($p \leq 0.05$ and 0.01) affected by the interaction of $D \times K$ levels. The interaction of $D_1 \times K_3$ resulted in the greatest values of Fv/Fm (0.86), PI (10.19 and 10.34), and SPAD (61.48 and 62.86), respectively, compared to the other interactions. Additionally, the interaction of $D \times S$ levels significantly increased PI ($p \leq 0.01$) and SPAD ($p \leq 0.05$). The $D_1 \times S_3$ interaction resulted in the greatest values of PI (8.84 and 9.06) and SPAD (58.47 and 59.41) in the

first and second seasons, respectively, compared to the other interactions. The interaction of $K \times S$ levels significantly ($p \leq 0.01$) affected sugar beet plant responses for SPAD in the 2019/2020 season. The $K_2 \times S_3$ produced the highest SPAD value (61.46), but the $K_1 \times S_1$ produced the lowest SPAD value (47.93) compared to the other interactions. The data presented in Tables S1–S4 show that root dimensions, root and top fresh weight plant^{-1} , and LAI were significantly ($p \leq 0.01$ and 0.05) affected by the interactions of $D \times K$ levels in both seasons. The interaction of $D_1 \times K_3$ resulted in maximum values for root length (35.48 and 36.30 cm), root diameter (15.34 and 16.05 cm), root fresh weight (1690.3 and 1657.8 g plant^{-1}), top fresh weight (1.18 and 1.25 kg plant^{-1}), and LAI (6.76 and 6.68) in the first and second seasons, respectively. The interaction of $D \times S$ levels significantly ($p \leq 0.01$) affected sugar beet growth traits with an increase in their responses as the applied S level increased in both seasons. The interaction of $D_1 \times S_3$ resulted in the maximum values for root length (34.09 and 34.79 cm), root diameter (15.18 and 15.54 cm), root fresh weight (1644.90 and 1608.90 g plant^{-1}), top fresh weight (1.17 and 1.23 kg plant^{-1}), and LAI (6.35 and 6.42) in the first and second seasons, respectively. The interaction of $K \times S$ levels significantly ($p \leq 0.01$) affected plant growth trait in both seasons. The interaction of $K_3 \times S_3$ resulted in maximum values for root length (35.78 and 36.44 cm), root diameter (16.18 and 16.05 cm), root fresh weight (1701.0 and 1694.2 g plant^{-1}), top fresh weight (1.23 and 1.28 kg plant^{-1}), and LAI (7.21 and 6.92) in the first and second seasons, respectively. The data presented in Table S3 and Figures S1–S7 show that impurity index, pure sugar (%), and purity (%) in the 2019/2020 season, and gross sugar (%) in both the 2018/2019 and 2019/2020 seasons were significantly ($p \leq 0.01$ and 0.05) affected by the interaction of $D \times K$ levels. The interaction of $D_1 \times K_3$ produced the highest values of gross sugar content (22.6% and 22.4% in the first and second seasons, respectively) and purity (91.26% in the second season), but the interaction of $D_2 \times K_1$ resulted in the highest values of impurity index (2.18 in the second season). Moreover, the interactions of $D \times S$ levels significantly ($p \leq 0.01$) affected alkalinity index response in the first season, while gross and pure sugar contents responded significantly in the second season. The interaction of $D_1 \times S_3$ resulted in the highest gross sugar content (21.3%) and alkalinity index (5.70), but the $D_1 \times S_2$ interaction resulted in the highest pure sugar content (19.1%) compared to the other interactions. The interaction of $K \times S$ levels significantly ($p \leq 0.01$) affected sugar beet trait responses concerning gross and pure sugar contents and the impurity index in the 2019/2020 season, and significantly ($p \leq 0.05$) affected Na^+ content in the 2018/2019 season. The interaction of $K_3 \times S_3$ produced the highest gross sugar content (22.2%) and pure sugar content (19.9%), the interaction of $K_1 \times S_1$ collected the highest Na^+ content (2.07 meq per 100g), while the interaction of $K_1 \times S_3$ resulted in the highest impurity index (2.19) compared with the other two-way interactions. Gross and pure sugar yields and R-KUE were significantly ($p \leq 0.01$) increased in both the 2018/2019 and 2019/2020 seasons, as well as root yield in the second season by the interaction of $D \times K$ levels. Furthermore, the biological yield in both seasons, root and top yields in the first season, harvest index, and R-SUE in the second season were significantly ($p \leq 0.05$) influenced by $D \times K$ levels (Tables S9 and S10 and Figures S8–S19). The interaction of $D_1 \times K_3$ gave the highest root yield (92.72 and 91.89 Mg ha^{-1}), top yield (33.77 and 34.94 Mg ha^{-1}), biological yield (126.47 and 126.83 Mg ha^{-1}), gross sugar yield (20.97 and 20.63 Mg ha^{-1}), pure sugar yield (19.23 and 18.83 Mg ha^{-1}), and R-SUE (0.30 kg root per kg S), while the lowest R-KUE (1.35 and 1.61 kg root per kg K) was produced by the interaction of $D_1 \times K_1$ and the lowest harvest index (0.78) was produced by the interaction of $D_2 \times K_1$ compared to the other interactions. Root, biological, gross, and pure sugar yields, R-KUE, and R-SUE in both seasons, as well as the harvest index in the second season were significantly ($p \leq 0.01$) influenced by the interaction of $D \times S$ levels. Additionally, top yield was significantly ($p \leq 0.05$) influenced in the first season by the same interaction (Tables S3 and S4; Figures S8–S19). The interaction of $D_1 \times S_3$ significantly collected the highest root yield (88.61 and 88.16 Mg ha^{-1}), top yield (33.13 and 34.22 Mg ha^{-1}), biological yield (121.74 and 122.38 Mg ha^{-1}), gross sugar yield (18.92 and 18.97 Mg ha^{-1}),

ha⁻¹), pure sugar yield (16.99 and 16.85 Mg ha⁻¹), and R-KUE (0.90 and 1.54 kg root per kg K). However, the lowest R-SUE (0.45 and 0.44 kg root per kg S) were produced with the interaction of D₁ × S₁ and the lightest harvest index (0.77) was produced with the interaction of D₂ × S₁ in the first and second seasons, respectively, compared to the other two-way interactions. Root, biological, gross, and pure sugar yields, R-KUE, and R-SUE in the 2018/2019 and 2019/2020 seasons, as well as top yield and harvest index in the second season and top yield in the first season, were significantly ($p \leq 0.01$ and 0.05) influenced by the interaction of K × S levels (Tables S3 and S4; Figures S8–S19). The interaction of K₃ × S₃ resulted in the significant highest root yield (91.73 and 89.11 Mg ha⁻¹), top yield (30.46 and 32.44 Mg ha⁻¹), biological yield (122.17 and 121.55 Mg ha⁻¹), gross sugar yield (20.25 and 19.97 Mg ha⁻¹), and pure sugar yield (18.37 and 17.94 Mg ha⁻¹). However, the lowest R-KUE (1.26 and 1.56 kg root per kg K) was obtained with the interaction of D₁ × S₃, and the maximum R-SUE (0.45 and 0.43 kg root per kg S) was produced with the interaction of D₃ × S₁ in the first and second growing seasons, respectively, compared to the other two-way interactions.

3.5. Effect of the Different Three-Way Interactions of the Three Factors Studied

Concerning the effect of the applied three-way interactions, Tables 3 and 4 display significant ($p \leq 0.01$) differences by the interaction of D₁ × K₃ × S₃ for the growth traits mentioned above in both seasons. The data listed in Tables 4 and 5 show that significant ($p \leq 0.01$) differences were reported for gross and pure sugar contents in the 2019/2020 season. The interaction of D₁ × K₃ × S₃ gave the maximum values of all juice quality traits compared with the other three-way interactions. The results in Tables 5 and 6 show significant ($p \leq 0.01$) variations for root, top, biological, gross, and pure sugar yields, R-KUE, and R-SUE in both seasons, and harvest index in the second season. The results in Figures S20 and S21 show that the interaction of D₁ × K₃ × S₃ gave the highest root yield (104.91 and 104.39 Mg ha⁻¹) and pure sugar yield (21.85 and 22.16 Mg ha⁻¹) in the first and second seasons, respectively, compared to the other three-way interactions.

3.6. The Direct and Indirect, Stepwise Regression, and Correlation Analyses

The data in Table 7 show that, under soil salinity (ECe = 8.96 dS m⁻¹) conditions, the direct (bolded and underlined values) and indirect effects of seven specified pure sugar yield (dependent variable) are related traits to pure sugar yield. The data of path coefficient analysis show that the root yield, pure sugar content, SPAD values, and LAI for sugar beet had positive direct effects with 0.62 and 0.65, 0.38 and 0.38, 0.01 and 0.0041, and 0.05 and 0.05 path coefficients in the first and second seasons, respectively, on pure sugar yield. Root length, root diameter, and root fresh weight traits had the highest indirect positive effects on pure sugar yield through root yield by 0.60 and 0.54, 0.60 and 0.54, and 0.61 and 0.57 in the 2018/2019 and 2019/2020 seasons, respectively. Furthermore, pure sugar content and SPAD values had the greatest indirect positive effects on pure sugar yield through root yield by 0.58 and 0.49, and 0.45 and 0.48 in the first and second seasons, respectively. In Table 8, correlation and regression data analysis between pure sugar yield and each of pure sugar content, root dimensions, root fresh weight, root yield, LAI, and SPAD values were calculated to concentrate on the relationship of the efficacious sugar beet traits interest. Highly significant ($p \leq 0.01$) positive correlations were found between pure sugar yield and root yield ($r = 0.966^{**}$ and 0.958^{**}) and between the dependent variable and each of pure sugar content ($r = 0.909^{**}$ and 0.866^{**}), root length ($r = 0.907^{**}$ and 0.944^{**}), and SPAD values ($r = 0.820^{**}$ and 0.983^{**}). Furthermore, highly significant positive correlations ($r = 0.921^{**}$ and 0.937^{**} , $r = 0.869^{**}$ and 0.920^{**} and $r = 0.876^{**}$ and 0.925^{**}) were observed between root yield and each of root length, root diameter, and root fresh weight in the first and second seasons, respectively. The stepwise regression in Table 9 shows the significant ($p \leq 0.01$) contribution of three traits (i.e., root yield, pure sugar content, and LAI) to the variations in pure sugar yield.

Table 7. A matrix of Pearson's correlation coefficient between pure sugar yield (Mg ha^{-1}) and other important traits estimated of sugar beet during two growing seasons under soil salinity ($\text{ECe} = 8.96 \text{ dS m}^{-1}$) conditions.

Character	Pure Sugar Yield (Mg ha^{-1})		Pure Sugar Content		Root Length (cm)		Root Diameter (cm)		Root Fresh Weight (kg plant^{-1})		Root Yield (Mg ha^{-1})		LAI		SPAD		
	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	
Pure sugar yield (Mg ha^{-1})	1	1	0.909 **	0.866 **	0.907 **	0.944 **	0.837 **	0.920 **	0.861 **	0.921 **	0.966 **	0.958 **	0.783 **	0.790 **	0.820 **	0.983 **	
Pure sugar content			1	1	0.740 **	0.756 **	0.639 **	0.711 **	0.691 **	0.684 **	0.778 **	0.694 **	0.669 **	0.620 **	0.728 **	0.706 **	
Root length (m)					1	1	0.881 **	0.921 **	0.886 **	0.947 **	0.921 **	0.937 **	0.827 **	0.827 **	0.878 **	0.893 **	
Root diameter (cm)							1	1	0.834 **	0.960 **	0.869 **	0.920 **	0.849 **	0.908 **	0.773 **	0.910 **	
Root FW (kg plant^{-1})									1	1	0.876 **	0.925 **	0.783 **	0.894 **	0.765 **	0.885 **	
Root yield (Mg ha^{-1})											1	1	0.749 **	0.765 **	0.789 **	0.885 **	
LAI													1	1	0.783 **	0.849 **	
SPAD																1	1

** $p \leq 0.01$, and ns; not significant. FW = fresh weight.

Table 8. Direct (bolded and underlined values), indirect effects of pure sugar yield (Mg ha^{-1}) components, and their correlations with pure sugar yield through two growing seasons under soil salinity ($\text{ECe} = 8.96 \text{ dSm}^{-1}$) conditions.

Character	Root Yield (Mg ha^{-1})		Pure Sugar Content		Root Length (cm)		Root Diameter (cm)		Root FW (kg plant^{-1})		SPAD Values		LAI	
	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Root yield (Mg ha^{-1})	0.50	0.46	0.58	0.49	0.60	0.54	0.60	0.54	0.61	0.57	0.45	0.48	<u>0.65</u>	<u>0.62</u>
Pure sugar content	0.23	0.26	0.27	0.28	0.26	0.27	0.27	0.24	0.28	0.28	<u>0.38</u>	<u>0.38</u>	0.26	0.30
Root length (cm)	0.0035	−0.02	0.0038	−0.02	0.0040	−0.02	0.0039	−0.02	<u>0.0042</u>	<u>−0.02</u>	0.0032	−0.01	0.004	−0.02
Root diameter (cm)	0.0015	−0.0003	0.0015	−0.0003	0.0016	−0.0003	<u>0.0017</u>	<u>−0.0004</u>	0.0015	−0.0004	0.0012	−0.0003	0.0015	−0.0004
Root fresh weight (kg plant^{-1})	−0.0043	0.02	−0.0043	0.02	<u>−0.0048</u>	<u>0.02</u>	−0.0046	0.02	−0.0046	0.02	−0.0033	0.01	−0.0044	0.02
SPAD values	0.0035	0.01	<u>0.0041</u>	<u>0.01</u>	0.0036	0.01	0.0037	0.01	0.0036	0.01	0.0029	0.01	0.0036	0.01
LAI	<u>0.05</u>	<u>0.05</u>	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.03	0.04	0.04	0.04
Total <i>r</i>	0.79 **	0.78 **	0.98 **	0.82 **	0.91 **	0.86 **	0.92 **	0.84 **	0.94	0.91 **	0.87 **	0.91 **	0.96 **	0.97 **

** $p \leq 0.01$, and ns; not significant. FW = fresh weight.

Table 9. Correlation coefficient (r), coefficient of determination (R^2), and standard error of the estimates (SEE) for predicting pure sugar yield (Mg ha^{-1}) in two growing seasons under soil salinity ($\text{ECe} = 8.96 \text{ d Sm}^{-1}$) conditions.

Season	R	R ²	SEE	Seg.	Fitted Equation
2018/2019	0.999	0.998	0.062	**	Pure sugar yield = $-5.859 + 0.182 \text{ root yield} + 0.309 \text{ pure sugar \%} + 0.06 \text{ LAI}$
2019/2020	0.999	0.997	0.068	**	Pure sugar yield = $-5.937 + 0.183 \text{ root yield} + 0.310 \text{ pure sugar \%} + 0.06 \text{ LAI}$

** $p \leq 0.01$.

4. Discussion

In the present study, in addition to soil salinity ($\text{ECe} = 8.96 \text{ dS m}^{-1}$; Table 1), its potassium (K^+) content is $39.124 \text{ mg kg}^{-1}$ soil, making it K^+ -poor soil. Additionally, saline soils often suffer from a deficiency of nutrients, including S [27], so the soil examined in this study is deficient in S. Therefore, it was necessary to supply the tested saline soil with sufficient amounts of K^+ (to antagonize the harmful Na^+ ion) and S in favor of sugar beet plants to be able to take their nutritional requirements to be robust and thus be able to resist/tolerate the soil salinity conditions. In addition to the nutritional factor, the key climatic factor affecting sugar beet productivity is temperature. For sugar beet plants to obtain sufficient thermal units throughout their growing season, it has been estimated the seasonal growing period of sugar beet plants to be approximately 200 days [45]. Thus, the sowing date of sugar beet has a great influence on the plant development and productivity through the adequate accumulation of thermal units, especially from the emergence stage until sugar beet plants reach the harvest stage [45]. Therefore, the date of sowing beets should have been early on the 1st of September to meet the required growth period for the plants to be supplied with the required thermal units, which would be reflected in the best growth and high yield with high quality under the tested salty soil conditions.

For the above reasons, the saline soil examined in this study was provided with three levels of K ($\text{K}_1 = 60$, $\text{K}_2 = 120$, and $\text{K}_3 = 180 \text{ kg K}_2\text{O ha}^{-1}$) and/or S ($\text{S}_1 = 175$, $\text{S}_2 = 350$, and $\text{S}_3 = 525 \text{ kg CaSO}_4 \text{ ha}^{-1}$), along with early sugar beet sowing on the 1st of September to provide all somewhat better environmental conditions for seed germination and seedling/plant growth until harvest to obtain the preferable yield with high quality for sugar beet plants grown under the adverse conditions of soil salinity.

The increased values recorded for Fv/Fm and PI (photosynthetic efficiency), along with SPAD (chlorophyll concentration) (Table 3), may be due to better climatic conditions with early sowing on the 1st of September which allowed plants to accumulate the maximum thermal units ($\text{GDD} = 3274.25$ and 3392.75) compared to the late sowing date on the 1st of October ($\text{GDD} = 3047.45$ and 3175.55) in the 2018/2019 and 2019/2020 seasons, respectively (Table 2). This finding allows for optimal early emergence, plant development, and leaf surface area, especially in the early stage of sugar beet plants. These increases in chlorophyll concentration and photosynthetic efficiency with K and S applications (especially the highest levels) [3,27] along with the early sowing date enabled plants to photosynthesize for more assimilates to obtain the highest root yield with high quality (Tables 3–6) under salt stress conditions. The increase in root dimensions, root and top fresh weight, and LAI may be due to the exposure of sugar beet plants to some favorable environmental conditions prevalent during the late growth stage and may be due to the increase in chlorophyll concentration and photosynthetic efficiency (Fv/Fm , PI, and SPAD), which resulted from the early sowing date employing accumulate higher thermal units for efficient photosynthesis increase leaf surface area to improve plant growth and increase the root weight of sugar beet [46].

The early sowing date (the 1st of September) also resulted in a marked increase in juice quality traits compared to the late sowing (the 1st of October) (Tables 4–6). These improvements in juice quality characteristics can be attributed to the appropriate climatic conditions, particularly the light and temperature required for the plant to perform well concerning the effective photosynthesis process [47]. This investigation reported a positive

response of the photosynthesis process to the effective temperature with sufficient light, water (with increasing the osmolyte K^+ by K application), and nutrients (acidification of growing medium with increasing S by S application) in favor of adequate chlorophyll concentration and photosynthetic efficiency (Table 3) for efficient production with high quality of sugar beet plants. The early sowing date resulted in a marked increase in gross and pure sugar contents, purity percentage, and alkalinity index, while it resulted in a marked decrease in impurities (e.g., Na^+ , K^+ , and α -amino N), impurity index, and loss sugar percentage (Tables 4 and 5). Some reports indicated that the early sowing of sugar beet markedly increases the sugar content, purity percentage, and pure sugar content [11,13]. Moreover, it was reported a positive correlation between climatic factors and sugar beet giving yield quality traits [48]. These findings can be attributed to that early sowing enables sugar beet plants to collect maximum energy for storing sugars in tubers. Besides, early sowing is likely to result in more possibilities for more favorable plant growth. These results are confirmed by those in [13,46,49]. Furthermore, the root, top, biological, gross sugar, and pure sugar yields, as well as R-KUE and R-SUE were markedly increased with the early sowing. These results can be attributed to better climatic conditions conferring higher chlorophyll concentration and photosynthetic efficiency (Fv/Fm, PI, and SPAD) that encouraged increased leaf surface area, root dimensions, root and top fresh weights, and gross and pure sugar contents, which reflected in the increased root, top, and biological yields, thus increasing the pure sugar yield. These results are confirmed by those in [13,46,49].

Merwad et al. [26] reported that increased salt tolerance in sugar beet plants has been correlated with increased K^+ availability in plant tissues. Salt damage in plants can be prevented by increasing the K^+ content due to its beneficial roles, directly as a protective osmoprotectant and indirectly by being used in antioxidation [50]. The beneficial effects of fertilization with K^+ , especially the highest level ($180 \text{ kg } K_2O \text{ ha}^{-1}$), of sugar beet plants growing under salt stress are related to its key roles in photosynthesis, protein synthesis, photosynthates translocation, control of ionic balance, and water availability [21]. Some investigations have confirmed, under salt stress, the importance of applying K^+ alone or in combinations in improving enzymatic activities, causing increased nutrient mobilization in the plant and translocation of photo-assimilates to active growing organs in the plant system to improve plant growth and high-quality production, all due to the improved chlorophyll concentration and photosynthetic efficiency (Fv/Fm, PI, and SPAD) [26,51,52]. Sufficient K^+ supply to saline soil ($EC_e = 8.96 \text{ dS m}^{-1}$) increases chlorophyll concentration (SPAD value) and leaf photosynthetic carbon, and thus also enhances light reaction routes (PSI and PSII) [53], which are strongly reflected in the increased growth and high-quality productivity for sugar beet plants. In this study, although applying K^+ to the examined salty soil increased the gross and pure sugar contents, quality percentage, and alkalinity index in the tubers of sugar beet, it markedly decreased impurities such as Na^+ , K^+ , α -amino N, impurity index, and loss sugar content, which may be attributed to the major role of K^+ in stimulating starch synthetase enzymes and the accumulation of carbohydrates that transfer from leaves to developing tubers of sugar beet, thus improving biochemical traits [54]. The major role of K^+ in inducing enzymatic activity and photosynthesis process is correlated to the synthesis of sucrose and the carrying of photosynthesized sucrose to phloem to raise sugar's level [55]. Mehrandish et al. [21] illustrated that applying K^+ increases recoverable sugar and reduces impurity traits. Moreover, increasing top and biological yields associate with increasing Fv/Fm, PI, SPAD value, top fresh weight, and leaf area index. These results confirm the results of this study. Table 6 shows that gross (root yield multiplied by gross sugar content) and pure sugar (root yield multiplied by pure sugar content) yields increased due to using K^+ for salty soil can be explained by the fact that K^+ plays a major role in enhancing all plant morpho-physiology, root yield, and gross and pure sugar contents, thus increasing gross and pure sugar yields of sugar beet plants. Additionally, the highest value of R-KUE was obtained using the highest K^+ that can be attributed to the highest K^+ level was associated with the highest increase in

root yield. Furthermore, the highest R-SUE was obtained when sugar beet plants received 525 kg CaSO₄ ha⁻¹ to give the highest root yield.

The inclusion of S in the plant's stress defense system increases plant tolerance to stresses, including salinity [27], and thus the application of S to saline soil alone or in combinations increased chlorophyll concentration and photosynthetic efficiency (Fv/Fm, PI, and SPAD values), which were reflected in the increased performance of sugar beet plants under salt stress (Tables 3–6). A report [27] indicates that applying S to salt-stressed plants increases glutathione pool (a compound containing S), which may lead to increased photosynthesis efficiency due to the critical role of S in photosynthesis functions and the improvement of the leaf chlorophyll concentration, thus increasing plant growth and yield characteristics. In this study, a gradual increase in S level from 175 to 525 kg CaSO₄ ha⁻¹ to salt-stressed sugar beet plants resulted in a gradual increase in chlorophyll concentration and photosynthetic efficiency (Fv/Fm, PI, and SPAD values), which were reflected in increased plant growth and yield characteristics with high quality. These positive results can also be attributed to that adding S to the soil may be enhanced soil properties and fertility in favor of the growing plants [27], causing an increase in the photosynthetic area in sugar beet plants that it gives maximum returns. Additionally, the impurity traits (Na, K, and α -amino N), impurity index, and loss sugar content were decreased by applying S, especially the highest level, thus increasing the gross and pure sugar content with high purity and quality percentages, and alkalinity index, while non-sugars decreased in salt-stressed sugar beet plants (Tables 4 and 5). The increase in yield traits and their quality can be illustrated based on the increases in growth traits, which in turn were achieved through increased chlorophyll concentration and photosynthesis efficiency, all due to the beneficial effects of S applied alone or in combinations (Tables 3–6).

Fertilizing strategy of saline soils (ECe = 8.96 dS m⁻¹) is very important to bring the nutrients into balance status in favor of growing plants. Applying K⁺ up to 180 kg K₂O ha⁻¹ with S application to these defective soils up to 525 kg CaSO₄ ha⁻¹ can help, as effective agronomical practice, these defective soils to become highly productive due to overcoming the effects of high salinity and encouraging increased salt tolerance in sugar beet to improve its productivity and industrial traits by increasing K- and S-use efficiency under dry environmental conditions.

Finally, various environmental foes, including the foes studied in this work, have negative impacts on plant growth. These negative impacts may exceed the natural tolerance capacity of stressed plants. In this case, the components of the stressed plant's defense system do not meet the requirements of adequate defense, and therefore the external use of auxiliary substances such as nutrients and other beneficial strategies helps the plants to increase the efficiency of their antioxidant defenses; thus, plants can perform efficiently under adverse conditions of environmental foes [3,4,8,56–59].

5. Conclusions

This work was conducted to shed light on the potential positive effects of potassium and sulfur applied to saline soil (ECe = 8.96 dS m⁻¹) to stimulate salt tolerance by promoting growth, pure sugar yield, and juice quality, as well as K- and S-use efficiency of sugar beet with two sowing dates in semi-arid regions. Early sowing date (the 1st of September) increased responses of morpho-physiological trait responses (root dimensions and weight; top fresh weight; Fv/Fm; PI; SPAD; LAI; juice quality; productivity; root, top, biological, gross, and pure sugar yields; and the alkalinity index; as well as K- and S-use efficiency) to soil fertilization with potassium (especially at a level of 180 kg K₂O ha⁻¹) and sulfur (especially at a level of 525 kg CaSO₄ ha⁻¹) under salt stress conditions. The application of potassium and sulfur induced salt tolerance in sugar beet plants by enhancing growth indices and sugar quality traits while reducing impurity traits (Na, K, and α -amino N), loss sugar content, and impurity index. Path coefficient analysis data showed that root yield, pure sugar content, SPAD, and LAI in sugar beet had positive direct effects with 0.62 and 0.65, 0.38 and 0.38, 0.01 and 0.0041, and 0.05 and 0.05 path coeffi-

cients, in the first and second seasons, respectively, on pure sugar yield. Highly significant ($p \leq 0.01$) positive correlations were found between pure sugar yield and root yield ($r = 0.966^{**}$ and 0.958^{**}), and between the dependent variable and each of pure sugar content ($r = 0.909^{**}$ and 0.866^{**}), root length ($r = 0.907^{**}$ and 0.944^{**}), and SPAD value ($r = 0.820^{**}$ and 0.983^{**}). Stepwise regression data showed that three traits (i.e., root yield, pure sugar (%), and LAI) contributed significantly ($p \leq 0.001$) to the variations in pure sugar yield. Soil application with potassium and sulfur with the above-mentioned doses can be assisted to correct their reductions in the saline soils to reduce salt stress effects on sugar beet plants. The results of our study will open new research prospects for fertilization strategy, one of the important factors for overcoming different abiotic stresses, especially salinity in climate change scenarios.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/agronomy11040806/s1>, Table S1: Photosynthetic efficiency (Fv/Fm, PI(%), and SPAD values), and root length (cm) of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Table S2: Root diameter, root fresh weight, and top fresh weight of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Table S3: Leaf area index (LAI), biological yield, harvest index, and purity content of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Table S4: Root yield, and top yield of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), during two growing seasons (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S1: Na⁺ (meq per 100 g) in 2018/2019 season and impurity index in 2019/2020 season of sugar beet as affected by the interactions of sowing dates (D) and potassium (K), (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S2: Na⁺ (meq per 100 g) in 2018/2019 season and impurity index in 2019/2020 season of sugar beet as affected by the interactions of potassium (K) and sulphure (S), (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S3: Gross sugar (%) and alkalinity index of sugar beet as affected by the interactions of sowing dates (D) and potassium (K), in 2018/2019 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S4: Gross and pure sugar (%) of sugar beet as affected by the interactions of sowing dates (D) and potassium (K), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S5: Gross sugar (%) and alkalinity index of sugar beet as affected by the interactions of sowing dates (D) and sulphure (S), in 2018/2019 season, (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S6: Gross and pure sugar (%) of sugar beet as affected by the interactions of sowing dates (D) and sulphure (S), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S7: Gross and pure sugar (%) of sugar beet as affected by the interactions of potassium (K) and sulphure (S), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S8: Gross and pure sugar yield (t h⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and potassium (K), in 2018/2019 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S9: Gross and pure sugar yield (t h⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and potassium (K), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S10: Gross and pure sugar yield (Mg h⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and sulphure (S), in 2018/2019 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S11: Gross and pure sugar yield (Mg h⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and sulphure (S), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S12: Gross and pure sugar yield (Mg h⁻¹) of sugar beet as affected by the interactions of potassium (K) and sulphure (S), in 2018/2019 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S13: Gross and pure sugar yield (Mg h⁻¹) of sugar beet as affected by the interactions of potassium (K) and sulphure (S), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S14: R-KUE (kg root kg K⁻¹) and R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and potassium (K), in 2018/2019 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S15: R-KUE (kg root kg K⁻¹) and R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and potassium (K), in 2019/2020 season (Mean \pm SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S16: R-KUE (kg root kg K⁻¹) and

R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and sulphure (S), in 2018/2019 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S17: R-KUE (kg root kg K⁻¹) and R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of sowing dates (d) and sulphure (S), in 2019/2020 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S18: R-KUE (kg root kg K⁻¹) and R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of potassium (K) and sulphur (S), in 2018/2019 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S19: R-KUE (kg root kg K⁻¹) and R-SUE (kg root kg S⁻¹) of sugar beet as affected by the interactions of potassium (K) and sulphur (S), in 2019/2020 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S20: Root yield (Mg ha⁻¹) and pure sugar yield (Mg ha⁻¹) of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), in 2018/2019 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions, Figure S21: Root yield (Mg ha⁻¹) and pure sugar yield (Mg ha⁻¹) of sugar beet as affected by the interactions of sowing date (D), potassium (K) and sulphur (S), in 2019/2020 season (Mean ± SE) under soil salinity (ECe = 8.96 dS m⁻¹) conditions.

Author Contributions: Conceptualization, A.A.A.M., M.M.R. and E.F.A.; data curation, A.A.A.M., M.M.R. and F.A.S.H.; formal analysis, A.A.A.M., E.F.A. and F.A.S.H.; investigation, A.A.A.M., M.M.R. and E.F.A.; methodology, A.A.A.M., M.M.R. and E.F.A.; resources, A.A.A.M., M.M.R., E.F.A. and F.A.S.H.; software, A.A.A.M., M.M.R. and F.A.S.H.; writing—original draft, A.A.A.M. and F.A.S.H.; writing—review and editing, M.M.R. and E.F.A. All authors have read and agreed to the published version of the manuscript.

Funding: The Deanship of Scientific Research at Taif University through the research number TURSP-2020/143 is acknowledged.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Acknowledgments: Authors are thankful to Taif University Researchers Supporting Project number (TURSP-2020/143), Taif University, Taif, Saudi Arabia for providing the financial support and research facilities.

Conflicts of Interest: The authors declare no conflict of interest.

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