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Article

How Irrigation Level and Soil Type Affect Nutritional Quality and Yield of Greenhouse Tomato Grown Under Mild Environmental Conditions

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Abstract

Cherry tomato is a highly demanding crop regarding temperature and water requirements. Considering that the climate crisis has already affected soil quality, water quality and quantity, and temperatures throughout the year, some cultivation practices may need to adapt to the new reality. This research aims to investigate whether soil type in a greenhouse (Zones 1 and 2), deficient irrigation (50% of the optimal irrigation according to the producer), or their interaction can affect the fruit production per plant and quality of cherry tomatoes. Evaluated parameters included total and monthly fruit production per plant, phenolic compounds, antioxidant activity, total soluble solids, and lycopene content. Results indicate that fruit production per plant was not significantly affected by any treatment or their interaction. Cherry tomato fruit quality was not dramatically affected by either soil type or irrigation level. To conclude, irrigation levels can be reduced by 50% without compromising tomato fruit quality and production per plant. These results can be a potential to adaptation to the climate crisis and water scarcity.

Keywords: water shortage; vegetables; climate crisis

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1. Introduction

The climate crisis has imposed abrupt increases in mean temperature, rainfall pattern variations, and the intensity of extreme phenomena, such as prolonged heatwaves and droughts. The Mediterranean climate is already characterized by warm, dry summers and mild, humid winters, while it is a climate crisis hot spot in Europe [1]. This extreme seasonal variation is challenging for crops such as tomato that thrive in warm regions with sufficient water availability during the growing season [2]. Tabletop tomato is nowadays almost exclusively cultivated in greenhouses, where some of the climate parameters can be partly managed, thus ameliorating the harsh conditions. On the other hand, greenhouse tomatoes can only be irrigated through technical means and not precipitation, leading to greater demands for human-provided water [3]. In addition, the interaction among climate conditions, soil properties, and cultivated plants affects the quantity and quality of the produce. Therefore, the ongoing climate crisis is expected to negatively affect agriculture in Mediterranean climate zones. Adaptation to these conditions demands novel strategies to ensure sustainable farming. Agriculture in the Mediterranean region, even in areas of the world with similar environmental conditions, demands water management due to water scarcity resulting from the climate crisis [4,5]. The design of new irrigation patterns requires extensive and targeted research on soil–water interactions with a view to limiting the provided water.

Cherry tomato is gaining popularity among greenhouse growers due to a number of reasons. It shows increasing demand by consumers for salads, sauces, and garnishes and has been established as a profitable vegetable with higher sales prices than regular-sized tomatoes. Moreover, cherry tomato is rich in vitamins (especially vitamin C and A) and antioxidants; thus, it has a high nutritional value [3,6,7]. The crop requires high amounts of water which are solely provided by irrigation systems, mainly drip, during greenhouse production. Drought is especially detrimental for its proper development, limiting the yield and product quality. For example, irregular water availability causes physiological disorders such as fruit cracking and blossom-end rot [8]. Therefore, irrigation must be precise and adjusted to each growth phase to avoid insufficient water. Sustainable water use is vital, especially in regions with limited water sources. The use of modern techniques for water management, such as the exploitation of sensors, is expected to enhance the monitoring of water requirements leading to increased water-use efficiency and less water being wasted [3,9].

Soil characteristics are crucial factors for plant growth and productivity. Soil texture, pH, organic matter content, cation exchange capacity (CAC), electrical conductivity (EC), and exchangeable sodium percentage (ESP) are common indicators of soil properties in soil analyses. Soil texture and structure are described by the proportion of sand, clay, and silt, and affect water-holding capacity as well as drainage [10]. CAC and pH determine nutrient availability, while EC and ESP are indicative of soil salinity and sodicity, respectively. Soil properties combined with irrigation levels are highly correlated with plant growth and development, as well as the yield and quality of crops [7].

Thus, this study aimed to investigate whether soil characteristics and irrigation volume affect cherry tomato production in a commercial greenhouse under mild conditions, addressing a great part of the global farming sector occurring in Mediterranean climate conditions, while partly controlling environmental conditions with a low cost and simple construction greenhouse.

2. Materials and Methods

2.1. Soil and Environmental Conditions

Before the cultivation establishment, soil samples were collected from three different spots of a commercial greenhouse in Tympaki (35.0729° N, 24.7686° E), Heraklion, Creta, Greece, after the input of manure and fertilizers. The greenhouse soil was divided into two zones (Zone 1 and Zone 2) based on characteristics such as color and composition, and samples were collected from each zone (Table 1). These samplings were crucial for evaluating soil conditions prior to irrigation treatments. The broader region of Heraklion faces temperatures during the day from 28 °C to 30 °C in summer months and 15 °C and 17 °C in the winter. It is characterized by dry and hot summers and wet yet mild winters. The average air and soil temperature during cultivation was 19.56 °C and 18.13 °C, respectively, while the average soil and air humidity was 31.12% and 78.81%.

Table 1. Soil analysis of the two soil types in the greenhouse. CEC is the cation exchange capacity, and ESP is the exchangeable sodium percentage.

Sample	Composition	pH	EC dS/m	$CaCO_3$ %	Organic Matter %	Sand %	Clay %	Silt %	Exchangable Na cmolc/kg	CEC cmolc/kg	ESP %
1	Zone 1 + manure + fertilizers	7.79	2.22	16.90	3.97	42	26	32	0.57	21.65	2.61
2	Zone 2 + manure+ fertilizers	7.65	1.74	15.40	2.96	42	26	32	0.55	18.62	2.93

2.2. Irrigation Levels

Plant irrigation was conducted using a drip irrigation system, according to the producer's standard practice. For this experiment, the drip irrigation system was modified to supply either 100% or 50% of the estimated water quantity by the producer's practice and experience, in both soil zones of the greenhouse. In each soil zone, each plant was irrigated with 191.13 L of water in total (100% irrigation) or 95.57 L (50% irrigation), from the first sampling when the irrigation treatment was implemented (until that day, all plants were supplied with 100% of the estimated water quantity, according to the producer's practice).

2.3. Plant Material

Greenhouse cherry tomato seedlings (LobelloF1) were transplanted on 26 July 2023 in both soil zones. Five plants from each irrigation level in each soil zone were selected and marked, and each plant was considered a replication. During cultivation and in frequent time frames, a total of five samplings of cherry tomatoes were conducted from the marked plants. The samples were sent within 24 h to the Laboratory of Vegetable Crops at the Department of Horticulture of Aristotle University of Thessaloniki for analysis and evaluation of quality parameters of the fruits.

The fruit samplings took place on the following dates:

- 1st sampling—1 November 2023
- 2nd sampling—20 December 2023
- 3rd sampling—27 February 2024
- 4th sampling—14 April 2024
- 5th sampling—25 June 2024

2.4. Fruit Production

Through the entire time of the cultivation, marketable cherry tomato fruits (damaged, shrunken, or infested fruits were discharged) were collected every month from the marked plants to calculate the monthly fruit production per plant for both soil zones and irrigation levels.

2.5. Fruit Quality Parameters

Cherry tomatoes from each replication were pulpified upon arrival at the laboratory. An adequate quantity of the pulp was infiltrated in order to define the total soluble solids content using an Atago PR-1 (Atago Co., Ltd., Tokyo, Japan) refractometer.

For the determination of lycopene content of the fruits, a modification of the procedure proposed by Mencarelli and Saltveit [11] was followed, and 1 g of pulp was mixed with 14 mL of 80% acetone. After centrifugation at 10,000 rpm for 10 min, the supernatant was filtrated through Whatman No. 1 filters into a 25 mL volumetric flask. Another 10 mL of 80% acetone was added to the remaining sediment and stirred at 150 rpm in the dark to prevent light-induced lycopene oxidation. The supernatant was also added to the volumetric flask, and the volume was adjusted to 25 mL with 80% acetone. Lycopene content was measured at 503 nm using a Jenway 6300, Cole-Parmer, Cambridge, UK, visible spectrophotometer.

The determination of total phenolic compounds was conducted using the Folin–Ciocalteu method [12], where 2.5 g of pulp sample was mixed with 80% MeOH, frozen for 24 h, and then filtrated. A 0.5 mL of the filtered extract was mixed with 2.5 mL of 10% Folin–Ciocalteu reagent and 2 mL of 7.5% Na_2CO_3 reagent. The mixture was heated for 5 min at 50 °C, and the absorbance was measured at 760 nm using a Jenway 6300 visible spectrophotometer.

Antioxidant activity was determined using the Ferric reducing antioxidant power (FRAP) assay [13]. A working solution of 0.3 M (pH 3.6) $CH_3COONa{\cdot}H_2O$, 40 mM TPTZ, and 20 mM $FeCl_3$ was used in a 10:1:1 ratio. Afterwards, 3 mL of the working solution was added to 100 µL of sample extract (2.5 g + 80% MeOH). The FRAP absorbance was measured at 593 nm using a Jenway 6300 visible spectrophotometer.

2.6. Statistical Analysis

Each sampling consisted of three replications per treatment, and each replication included 12 cherry tomato fruits.

Two-way ANOVA was performed to determine the treatment effect significance, as well as Tukey's range test, using IBM SPSS Statistics, 29.0.0.0 (241) software.

3. Results and Discussion

Effective irrigation management is essential during tomato cultivation to maintain the optimum yield and quality while saving water resources. Reduced or deficit irrigation strategies can contribute to this by improving water productivity and water-use efficiency [14,15]. Adopting deficit irrigation strategies can also help mitigate environmental issues such as nutrient leaching and salt accumulation caused by excessive irrigation, thereby improving soil health [16]. Nevertheless, irrigation water quality should be carefully taken into consideration when implementing these strategies in order to prevent opposite results [17].

Fruit production per plant was not significantly affected, positively or negatively, by either soil zone or either level of irrigation (Table 2). However, in Zone 1 of the greenhouse with 100% irrigation level, the absolute value of fruit production per plant tended to be higher (Figure 1).

Monthly fruit production per plant was not affected from 29 October 2023 until 20 Jenuary 2024. On 3 February 2024, 50% irrigation significantly reduced fruit production per plant (Table 3), with all treatments recording the lowest fruit production per plant of the cultivation (Figure 2). On March 1st, each soil zone and its interaction with each irrigation level significantly affected fruit production per plant (Table 3), with Zone 1 50% marking the highest value and Zone 2 50% the lowest (Figure 2). On 11 May 2023 (maximum fruit production per plant of the cultivation) and 25/6, 100% irrigation significantly affected fruit production per plant (Table 3) (Figure 2). However, fruit production per plant, as mentioned above, was not affected either positively or negatively by any of the soil types or irrigation levels (Figure 1). Furthermore, during cultivation, the course of fruit production per plant was the same regardless of any of the treatments.

Table 2. ANOVA on fruit production per plant of the tomato cultivation, with soil zone (1 and 2) and irrigation level (100% and 50%) treatments. Values indicate the *p*-value (significance level $p < 0.05$).

Treatment	Fruit Production Per Plant (kg)
Soil Zone (A)	0.16
Irrigation Level (B)	0.05
A × B	0.38

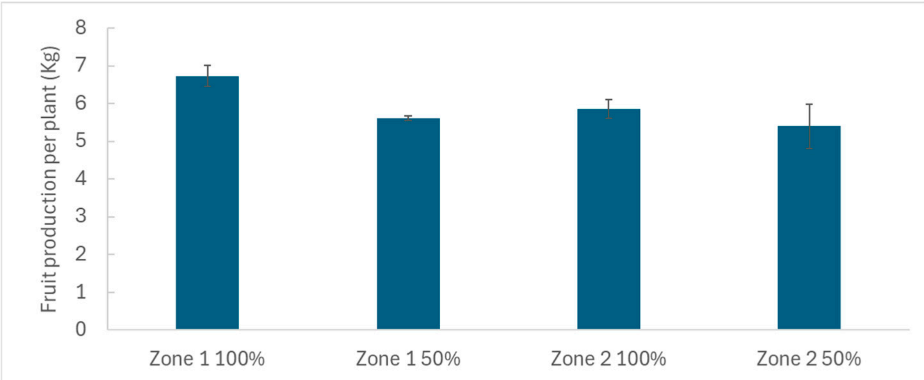

Figure 1. Fruit production per plant of all four treatments of soil zone (1 and 2) and irrigation level (100% and 50%) in tomato cultivation. Bars represent average values ± SE; nonmatching letters indicate significant differences ($p < 0.05$).

Table 3. ANOVA on fruit production per plant per month of the tomato cultivation, with soil zone (1 and 2) and irrigation level (100% and 50%) treatments. Values with asterisk indicate the *p*-value (significance level $p < 0.05$).

Fruit Production Per Plant/month	29 October 2023	11 November 2023	16 December 2023	30 December 2023	20 Jenuary 2024
Soil Zone (A)	0.29	0.29	0.96	0.94	0.13
Irrigation Level (B)	0.37	0.68	0.61	0.12	0.53
A × B	0.81	0.36	0.51	0.35	0.23
	3 February 2024	**1 March 2024**	**27 April 2024**	**11 May 2024**	**25 June 2024**
Soil Zone (A)	0.17	0.35 *	0.46	0.9	0.32
Irrigation Level (B)	0.04 *	0.17	0.69	0.028 *	0.048 *
A × B	0.81	0.025 *	0.64	0.38	0.05

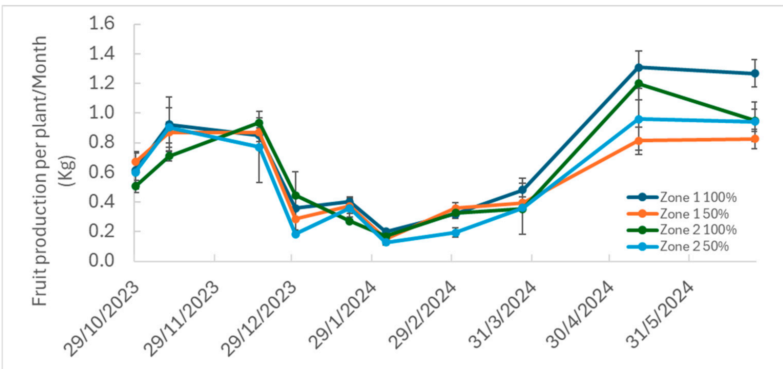

Figure 2. Fruit production per plant per month of all four treatments of soil zone (1 and 2) and irrigation level (100% and 50%) in tomato cultivation. Dots indicate average values.

Quite similarly to our results, Ghannem et al. [18] found similar tomato fruit production per plant when 50%, 75%, and 100% irrigation was applied during the vegetative and first truss stages.

A study with eggplants revealed significantly greater yield, as well as fruit (i.e., length, width, and number among others) and plant (i.e., height, stem diameter, and leaf proportions) morphological characteristics when plants were treated with 50% deficient water compared with full irrigation [19].

During a tomato experiment, a soil moisture content at 80% of field water capacity proved to be the most water-efficient moisture content level without significant yield reduction compared with treatments involving 100%, 70%, and 60% field water capacity [20].

One key finding was that a 50% reduction of irrigation water compared with the local practices resulted in similar fruit quality and production per plant throughout a cultivation season, after growth in two different but typical soil types in the Mediterranean. This is a clear indication that professional farmers in Crete irrigate using considerably higher water amounts than required by cherry tomatoes for optimum growth. From the above, it is highly possible that irrigation water volume can be significantly reduced without compromising the fruit production per plant or the overall quality.

During the cultivation period of this study, no specific pattern was found regarding the influence of soil type, irrigation level, or their interactions on any of the evaluated parameters. In some samplings, soil type affected antioxidant capacity, and phenolic content, total soluble solids content (°Brix), and lycopene content (in samplings 1, 3, and 5, respectively) (Table 4). Irrigation level had a significant effect on samplings 1, 2, and 5, affecting antioxidant capacity, total soluble solids content (°Brix), and lycopene content, respectively (Table 4). The interactions of the two factors (soil type and irrigation level) affected antioxidant capacity (in samplings 1 and 2), lycopene content (sampling 3), and total soluble solids content (°Brix) in sampling 5 (Table 4).

Table 4. ANOVA on total soluble solids content, phenolic content, antioxidant capacity, and lycopene content in tomato fruits, with soil zone (1 and 2) and irrigation level (100% and 50%) treatments on each of the five sampling days. Values with asterisk indicate the p-value (significance level $p < 0.05$).

	Treatment	Total Soluble Solids	Phenolic Content	Antioxidant Capacity	Lycopene
1st Sampling	Soil Zone (A)	0.14	0.3	0.04 *	0.05
	Irrigation Level (B)	0.14	0.3	0.04 *	0.05
	A × B	0.14	0.3	0.04 *	0.05
2nd Sampling	Soil Zone (A)	0.56	0.08	0.07	0.99
	Irrigation Level (B)	0.001 *	0.16	0.05	0.24
	A × B	0.39	0.99	0.03 *	0.21
3rd Sampling	Soil Zone (A)	0.88	0.004 *	0.71	0.005 *
	Irrigation Level (B)	0.06	0.59	0.77	0.57
	A × B	0.51	0.86	0.43	0.00 *
4th Sampling	Soil Zone (A)	0.03 *	0.76	0.20	0.91
	Irrigation Level (B)	0.48	0.37	0.52	0.17
	A × B	0.72	0.08	0.48	0.33
5th Sampling	Soil Zone (A)	0.003 *	0.17	0.51	0.01 *
	Irrigation Level (B)	0.22	0.08	0.69	0.03 *
	A × B	0.04 *	0.61	0.96	0.30

Lycopene is an active biological compound, a carotenoid, well known for its antioxidant and anti-cancer properties [21]. It is proven that mild stress during cultivation of cherry tomato plants can lead to an increase in antioxidant compounds, such as lycopene and polyphenols, by regulating metabolic procedures [22]. One the other hand, research has also shown that fully irrigated tomato plants demonstrate higher nutritional quality [23].

Lycopene content in cherry tomatoes marked its peak at the beginning of the treatments (sampling 1) with all four treatments not deferring significantly. In the second sampling, the content was reduced but still did not differ significantly among treatments. During the third sampling, cherry tomatoes showed the lowest lycopene content for treatments Zone 1 and 2 100% and Zone 1 50%. In this sampling, the Zone 2 50% treatment increased the lycopene concentration to 3.48 (mg/g f.w), which was significantly higher than that of Zone 1 50% and Zone 2 100%. In the fourth sampling, lycopene content increased for all treatments but not significantly among them. In the fifth sampling, Zone 2 100% had the highest lycopene content and was significantly higher than Zone 1 50% (Table 5). Some studies on tomato cultivation have correlated full irrigation with reduced lycopene concentration while increasing yield, whereas some other research refers to lycopene concentration as a cultivar-related characteristic [3,24]. Compared with our results, a study on tomato cultivation, rainfed and irrigated, found reduced lycopene content in irrigated fruits, indicating that regulated inputs, such as those used in our research, conclude in higher quality fruits regarding lycopene content [21].

Table 5. Comparison of average values of antioxidant capacity, total soluble solids content, phenolic content, and lycopene content in tomato fruits, with soil zone (1 and 2) and irrigation level (100% and 50%) treatments on each of the five sampling days. Different letters indicate statistical differences between treatments in each sampling. Values indicate average values ± SE (significance level $p < 0.05$).

	Treatment	Total Soluble Solids Brix (°)	Phenolic Content (mg/g f.w)	Antioxidant Capacity (μg/g f.w)	Lycopene (mg/100 g f.w)
1st Sampling	Zone 1 100%	7.67 ± 0.13 a	0.65 ± 0.01 a	172.3 ± 2.54 b	7.18 ± 0.20 a
	Zone 1 50%	7.67 ± 0.13 a	0.65 ± 0.01 a	172.3 ± 2.54 b	7.18 ± 0.20 a
	Zone 2 100%	7.40 ± 0.06 a	0.69 ± 0.03 a	183.8 ± 3.01 a	6.43 ± 0.18 a
	Zone 2 50%	7.40 ± 0.06 a	0.69 ± 0.03 a	183.8 ± 3.01 a	6.43 ± 0.18 a
2nd Sampling	Zone 1 100%	7.80 ± 0.12 b	1.10 ± 0.04 a	226.9 ± 4.03 a	3.78 ± 0.21 a
	Zone 1 50%	8.23 ± 0.13 ab	1.16 ± 0.05 a	225.9 ± 2.90 ab	3.16 ± 0.05 a
	Zone 2 100%	7.77 ± 0.09 b	1.18 ± 0.03 a	208.8 ± 5.40 b	3.45 ± 0.33 a
	Zone 2 50%	8.40 ± 0.10 a	1.24 ± 0.04 a	227.8 ± 2.43 a	3.48 ± 0.26 a
3rd Sampling	Zone 1 100%	6.63 ± 0.38 a	1.09 ± 0.01 a	232.3 ± 14.93 a	2.75 ± 0.07 a
	Zone 1 50%	7.53 ± 0.13 a	1.12 ± 0.04 a	226.1 ± 3.06 a	1.41 ± 0.14 b
	Zone 2 100%	6.80 ± 0.46 a	0.96 ± 0.02 a	227.1 ± 16.56 a	1.94 ± 0.23 b
	Zone 2 50%	7.27 ± 0.09 a	0.97 ± 0.06 a	240.1 ± 4.16 a	3.48 ± 0.20 a
4th Sampling	Zone 1 100%	8.77 ± 0.15 a	0.94 ± 0.03 a	202.5 ± 7.08 a	3.71 ± 0.43 a
	Zone 1 50%	8.87 ± 0.07 a	0.91 ± 0.01 a	202.0 ± 4.58 a	4.57 ± 0.47 a
	Zone 2 100%	9.37 ± 0.38 a	0.88 ± 0.02 a	185.9 ± 8.64 a	4.10 ± 0.06 a
	Zone 2 50%	9.67 ± 0.34 a	0.96 ± 0.04 a	196.9 ± 9.75 a	4.26 ± 0.19 a
5th Sampling	Zone 1 100%	9.83 ± 0.09 b	0.91 ± 0.02 a	197.1 ± 5.76 a	3.59 ± 0.23 ab
	Zone 1 50%	10.20 ± 0.50 b	0.97 ± 0.01 a	201.1 ± 2.88 a	2.88 ± 0.15 b
	Zone 2 100%	11.90 ± 0.17 a	0.95 ± 0.04 a	204.2 ± 9.52 a	4.03 ± 0.26 a
	Zone 2 50%	10.70 ± 0.31 ab	1.06 ± 0.07 a	209.3 ± 18.88 a	3.74 ± 0.03 ab

Fruit quality over time was irregular and dependent on the harvest period, highlighting the dynamic nature of plant–environment interactions. For example, the increased lycopene observed in Zone 2 at 50% irrigation during the third sampling date was possibly due to mild water stress, which is known to enhance the biosynthesis of secondary metabolites such as carotenoids. Controversial results in nutritional quality (lycopene content, antioxidant compounds) may lead to questions regarding what characteristics are variety dependent, what irrigation level is considered optimum, or what level is considered excess according to research and, in our case, the producer.

The phenolic content of cherry tomatoes followed the same course in almost every sampling, except the third one, where treatments of Zone 1 100% and 50% had higher but not significantly different values than Zone 2 100% and 50%. In all other samplings, there were no significant differences between treatments (Table 5).

Antioxidant activity followed the same course for all treatments during the cultivation period. Initially, both Zone 1 treatments appeared to have significantly lower antioxidant activity than both Zone 2 treatments. In the second sampling, Zone 2 100% noted significantly lower antioxidant capacity than Zone 1 100% and Zone 2 50%. In the subsequent samplings, there were no statistical differences among treatments regarding antioxidant activity (Table 5).

In all four treatments, total soluble solids content followed the same pattern during the cultivation period. However, the 100% irrigation treatment of both soil zones in the second sampling noted significantly lower total soluble solids content in comparison with Zone 2 at 50% irrigation. In the fifth sampling, marking the end of the cultivation, the 50% and 100% irrigation treatments in Zone 1 had significantly reduced total soluble solids content compared with Zone 2 100% (Table 5).

In another study, tomatoes deficiently irrigated at 0.6 or 0.8 of evapotranspiration (ET) during the vegetative stage exhibited a similar fruit yield and even enhanced quality in terms of total soluble solids content, acidity, ascorbic acid, and color index (related to lycopene content) compared with the control plants irrigated at 1.0 ET [25].

Similar to previous findings, our results could be useful in supporting sustainability during tomato production, especially in regions affected by water scarcity such as arid and semi-arid areas with a Mediterranean climate.

The increased Brix° in certain samples from the 50% irrigation treatments can be explained by the limited water volume in fruits, which led to greater sugar concentration.

As far as the soil is concerned, the greenhouse was already divided with a corridor in two sections by the producer. There was a difference in the color of the soil at first sight, as one side was redder than the other. Therefore, soil analysis was conducted in both sections, and cherry tomato plants were established in each section of the greenhouse. The soil analysis resulted in no drastic differences between soil types; however, it was found to be useful to investigate any effect of such little difference in soil on fruit production and quality of cherry tomato plants.

The two zones of soil type in the greenhouse affected the total soluble solids content and lycopene content, as previously mentioned above; however, according to their characteristics, neither of the zones is considered problematic in terms of Greek soils. Furthermore, it is proven in the literature and by the levels in this study that electric conductivity does not affect the yield or quality of tomato plants [26]. In most research, an electric conductivity level of soil at around 2 dS/m is used as a control and not as a treatment [27].

4. Conclusions

An irrigation quantity reduced by half of that used in the local practices did not impose negative effects on the overall fruit quality and production per plant of cherry tomatoes grown in a greenhouse in Crete, Greece—a region with mild environmental conditions during winter months. Our findings highlight the fact that strategic water deficiency can be a significant sustainable management tool to tackle the problems of limited water availability in drought-affected regions, such as the Mediterranean. It is concluded that cherry tomato plants can be cultivated with considerably less water during mild winter months in soils with such characteristics, without compromising the fruit production per plant, while also enhancing the fruit quality in some cases.

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Data Availability Statement: All data are contained within the article.

Conflicts of Interest: There are no conflicts of interest considering this research.

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