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Enhancing Tomato Productivity and Quality in Moderately Saline Soils through Salicornia-Assisted Cultivation Methods: A Comparative Study

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Abstract: The presence of high salt in soils is a substantial abiotic constraint for agricultural activities worldwide, particularly in Mediterranean regions. Researchers have discovered a simple and efficient way to repair soils that have suffered from excessive salt use. They use plants that can overcome salt, like halophytes, to improve the soil quality. This research aimed to evaluate the tomato productivity and quality cultivated using different methods. We look at three different ways to grow tomatoes with the halophyte *Salicornia europaea* L. in a moderately salty soil: monoculture (only tomatoes), intercropping (mixed cultivation), and sequential cropping (growing tomatoes where halophytes were grown before). We considered how the different ways of managing crops affected tomato yield, biochemical factors in tomato plants (like phenolic and flavonoid contents), antioxidant levels, carotene profiles, and fruit quality and production. Sequential cropping showed the highest tomato productivity, while intercropping exhibited high concentrations of total phenolics, total flavonoids, carotenoids, and antioxidant capacity. The tomatoes had a sweet taste due to the higher total soluble solid content (TSSC) and maintained their quality due to the higher titratable acidity (TA).

Keywords: saline agriculture; halophytes; antioxidant capacity; flavonoids; phenols; carotenoids; intercropping; sequential cropping

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1. Introduction

In recent years, climate change has become a pressing global issue, with rising temperatures and shifting precipitation patterns affecting various aspects of the environment, including water supplies and agricultural practices [1]. The Mediterranean region, in particular, is projected to experience significant drying and warming, making it a hotspot for future climate change scenarios. These changes have significant implications for crop growth and productivity, as well as for food security in the face of a growing human population. In order to address these challenges, it is crucial to explore innovative and sustainable agricultural practices that can mitigate the effects of climate change and enhance crop resilience [2].

Soil salinity is a significant abiotic factor that limits agricultural productivity and has deleterious effects on crop growth. When soil becomes saline, the high salt concentrations create an osmotic stress on plants, affecting their ability to take up water and nutrients. This can lead to reduced crop yields and poor plant health [3,4]. In regions with semi-arid and arid environments, such as the Mediterranean, where water scarcity is already a concern, soil salinity exacerbates the challenges faced by farmers. Therefore, finding crops that can tolerate higher salt concentrations is crucial for sustainable agriculture in these regions [5,6].

Halophyte plants are an essential component of saline agriculture, a nature-based solution that can be adopted to allow sustainable production under these conditions [7]. By definition, halophytes are plants that can complete their full growth cycle and reproduce under salinities of 200 mM or higher, thanks to the evolution of unique physiological adaptations that allow them to tolerate harsh conditions and salinity levels that are toxic to most plants. Due to their high capability of salt extraction, many halophytes can support climate-smart agriculture, as, for example, when cultivated in consociation or rotation systems with conventional crops. By contributing to the desalination of saline soils as they are able to extract and accumulate salts in their tissues, halophytes enhance soil quality and expand the available land surface, help to restore conditions for traditional agriculture, and can provide additional benefits because their biomass can be used for several purposes, such as food, feed, source of bioactive compounds, or fibers. [8].

Among halophytes, the Salicornia species are an excellent alternative for cultivation in the Mediterranean region to combat the issue of land degradation [9]. Salicornia is an annual plant that, thanks to its many adaptation mechanisms, can withstand high salt concentrations of at least 200–500 mM [10]. In addition, its nutritional content and salty taste make Salicornia a popular delicacy in European markets, where it is distributed as a unique vegetable [11]. Nevertheless, its market necessitates the implementation of effective agronomic strategies for either large- or medium-scale production [12].

Intercropping and sequential cropping systems have gained recognition as effective approaches to maximize agricultural productivity while minimizing farmed areas. These methods involve growing different crops together or in sequence, allowing for better resource utilization and complementarity. In the context of salt-affected soils, intercropping with salt-extracting plants, such as Salicornia, can help in mitigating ion toxicity and reducing soil salinity [13,14]. By intercropping them with Mediterranean agricultural plants, such as tomatoes, farmers can not only utilize hyperaccumulating plants for desalination techniques but also meet the increasing demand for these crops in the market. This integration of salt-tolerant crops with traditional crops can enhance soil quality, increase land availability, and contribute to sustainable agricultural practices [15].

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop, notably in the Mediterranean region, where it accounts for 20% of global production, with an estimated 180 million tons produced globally in 2021, 6.7 million tons of which has been produced in Italy [16]. Tomato is classified as having a moderate tolerance to salinity. This means that, if the electrical conductivity (EC) of the soil exceeds 2.5 dS m^{-1}, it could lead to a decrease in tomato crop yields [17].

The goal of this study was to evaluate the effectiveness of intercropping and sequential cropping systems with the halophyte *S. europaea* L. in increasing the productivity of tomato in a moderately salty soil under greenhouse conditions. We aimed to find out how the systems (intercropping and sequential cropping) affected not only the yield but also the quality of tomato production by determining the levels of bioactive compounds, such as phenols, flavonoids, and carotenoids, and the antioxidant activity. By examining these factors, we aimed to assess the potential benefits and feasibility of using intercropping or rotation with Salicornia as a strategy to enhance tomato crop resilience in salt-affected soils.

2. Materials and Methods

2.1. Materials

All solvents used for HPLC analysis were HPLC grade and purchased from Merck (Merck KGaA, Darmstadt, Germany). All chemicals of analytical grade, as well as analytical standards, were procured from Merck (Merck KGaA, Darmstadt, Germany).

2.2. Plant Material, Experimental Design, and Sample Collection

Field trials were conducted in greenhouse facilities at the experimental station “Podere Rottaia” of the Department of Agriculture, Food, and Environment of the University of Pisa (43°40′30.7′′ N 10°18′38.6′′ E), near the seacoast, during the spring–summer seasons.

Both Salicornia and tomato plants were purchased from a plant nursery and were then transplanted into the salt-affected soil of the experimental site. Salicornia cultivation started the year before tomato transplant. The pH in the top 15 cm of the soil where the experiment took place was measured to be 7.4 ± 0.22. The electrical conductivity (EC) was 1.66 ± 0.07 dS m^{-1}, and the soluble sodium (Na) concentration was 814 ± 19 mg kg^{-1}.

The plots (5 m × 4 m) were arranged in a randomized block design. The experimental design involved tomato in monoculture (MC), tomato in mixed cultivation with Salicornia (intercropping, IC), and tomato cultivated in monoculture where Salicornia plants were grown for one year before tomato cultivation (sequential cropping, SC) (Figure 1). Salicornia plots consisted of two double rows of twenty-five plants each (for a total of 100 plants per plot). The tomato plots consisted of two rows of thirteen tomato plants. IC plots consisted of two rows of thirteen tomato plants each, with twenty-five Salicornia plants cultivated on each side of the two tomato rows. Each plot was duplicated. Pictures of the greenhouse where the experiment was performed are displayed in Supplementary Figure S1. The experiment was conducted twice during the 2022 spring–summer seasons: once from April to June (first trial) and the other from July to September (second trial). Additionally, productivity data from the 2021 cultivation cycle, which included tomatoes grown in MC and IC with Salicornia but excluded the SC cultivation method, are provided as supplementary material (Supplementary Figure S2). The SC cultivation method indeed was not present in 2021 because the tomato plants would have replaced Salicornia starting from the following year. These supplementary data help to better contextualize and discuss the results.

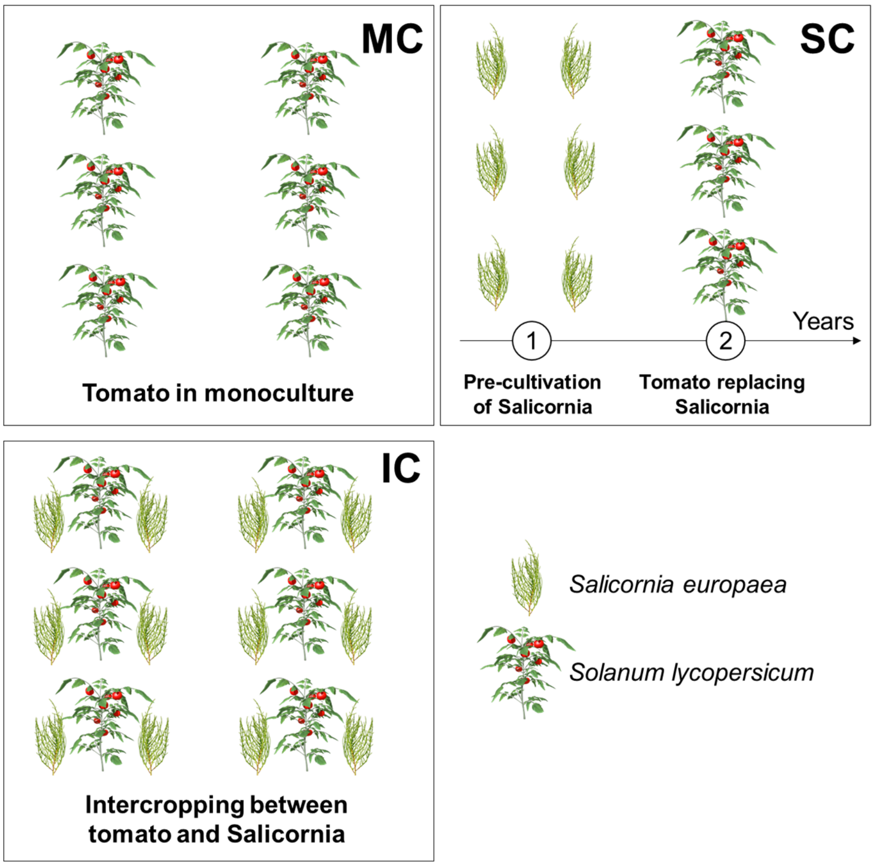

Figure 1. Scheme of the experimental design setup. Tomato monoculture (MC), tomato–Salicornia intercropping (IC), and tomato sequential cropping (SC) in which Salicornia plants were cultivated in monoculture during the first year of experimentation and replaced by tomato plants during the second year.

2.3. Tomato Fruit Production and Quality

The number of red ripe fruits produced by each plant was recorded. The total fruit weight per plant and the mean weight of fruit were measured. The data collected at the three different time points were used to calculate the total output per plant. The fruit firmness (FF) was evaluated by employing a penetrometer equipped with a 5 mm probe and expressed as Newton (N). The assessment was conducted on a flat surface by removing the skin from two opposing portions on the equatorial side of each fruit. The juice of twelve fruits from each cultivation system was passed through a 1 mm sieve and the titratable acidity (TA, expressed as % citric acid) [18], pH, and total soluble solid content (TSSC, expressed as °Brix) were evaluated. The sugar–acid ratio [19] and the ripening index (RPI) [20] were calculated by the following equations:

$$\text{Sugar-acid ratio} = \text{TSSC}/\text{TA}$$

$$\text{RPI} = \ln(100 \times \text{FF}/(\text{TSSC}/\text{TA}))$$

2.4. Extraction and Quantification of Total Phenolics and Flavonoids and Determination of Antioxidant Capacity

Samples from twelve fruits per cultivation system were extracted with 80% (v/v) aqueous methanol [21]. The total phenolic concentration was assayed with the Folin–Ciocalteu method [22], recording the absorbance of the reaction mix at 750 nm with an Ultrospec 2100 pro-UV–vis spectrophotometer (Amersham Biosciences, Slough, UK). The total phenolic concentration was expressed as milligrams of gallic acid equivalents (GAE) g^{-1} FW. The flavonoid concentration was determined following the protocol by Kim et al. [23], measuring the absorbance of the reaction mixture at 510 nm. The flavonoid concentration was expressed as mg of catechin equivalents (CE) g^{-1} FW. The antioxidant activity of the hydroalcoholic extract was determined by the ABTS assay (2,2-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)). The ABTS test was carried out following the procedure reported by Re at al. [24] based on the ability of antioxidants to reduce pre-formed ABTS•+ radicals to ABTS. The absorbance of the reaction mix was read at 734 nm after 4 min of incubation, and the percentage inhibition was calculated against a blank control. The results were expressed as μmol Trolox equivalent (TE) g^{-1} FW.

2.5. Extraction of Carotenoids and HPLC Analysis

Carotenoids were extracted from twelve fruits per cultivation method under dimmed room light in a mixture of HPLC-grade methanol, hexane, and acetone (1:1:1 ratio). Briefly, homogenized tomato samples (0.5 g) were added to 6 mL of extraction mixture, followed by a 30 min stirring in ice bath. Then, 2 mL of Milli-Q water was added to the sample tube and vortexed vigorously. To separate the hydrophilic phase from the lipophilic phase, the sample tubes were centrifuged for 30 s at 1500 rpm. The carotenoid-containing non-polar phase was then filtrated through 0.2 μm filters (Sartorius Stedim Biotech, Goettingen, Germany) and immediately subjected to HPLC analysis (HPLC Vanquish Core, diode array detector CG; Thermo Fisher Scientific, Waltham, MA, USA). Pigments were separated using a Zorbax ODS column (SA, 5 μm particle size, 250 mm × 4.6 mm; Phenomenex, Castel Maggiore, Italy), set at 20 °C throughout the run. The flow rate, injection volume, and temperature of the autosampler were set to 0.8 mL min^{-1}, 20 μL, and 20 °C, respectively. The diode array detector was set at 286 nm for the detection of phytoene, 350 nm for phytofluene, 450 nm for β-carotene, and 470 nm for lycopene. Concentration of the pigments (μg g^{-1} FW) was determined using calibration curves of lutein, lycopene, and β-carotene commercial standards. The phytofluene and phytoene concentrations were expressed as β-carotene equivalents. The elution gradient is reported in Table 1.

Table 1. HPLC elution gradient used for lycopene and carotenoid analysis.

Time (min)	Solvent A [1] (%)	Solvent B [2] (%)
0	82	18
20	76	24
30	58	42
40	39	61
45	82	18

[1] Solvent A (acetonitrile); [2] solvent B (methanol/hexanol/dichloromethane, 1:1:1).

2.6. Statistical Analysis

Data are expressed as the mean ± standard deviation (SD, n = 12). All results were assessed by one-way analysis of variance (ANOVA) at a significance level of 0.05 ($p < 0.05$), followed by Duncan's post hoc test. JMP software (JMP®, Version 16, SAS Institute, Inc., Cary, NC, USA) was used to process the data.

3. Results

3.1. Effect of Cultivation Method on Tomato Productivity

The productivity of the tomato plants significantly differed among MC, IC, and SC. Specifically, a lower number of fruits per plant (−56%, Figure 2A; −41%, Figure 2E) and per plot (−56%, Figure 2C; −32%, Figure 2G) was produced by tomato plants intercropped with Salicornia. A similar trend was observed for fruit weight both in the first (−85% per plant and per plot; Figure 2B,D) and in the second (−53% and −47% per plant and per plot, respectively; Figure 2F,H) trial.

SC displayed a better performance than IC for all the parameters and in both trials, while only slight variations, mostly not significant, were observed compared to MC.

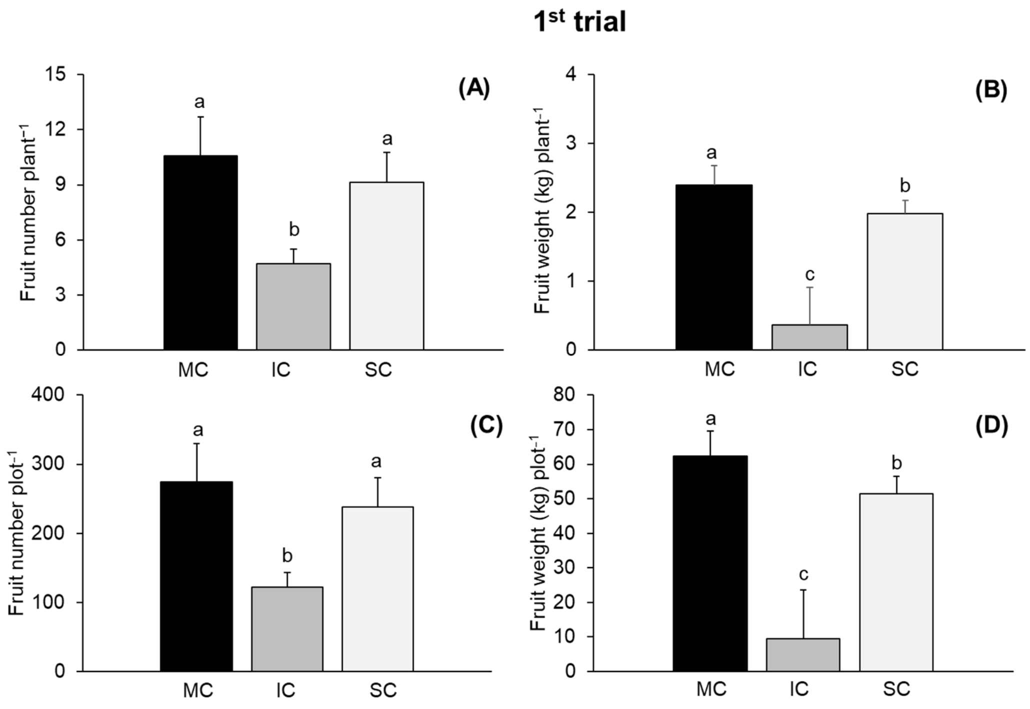

Figure 2. *Cont.*

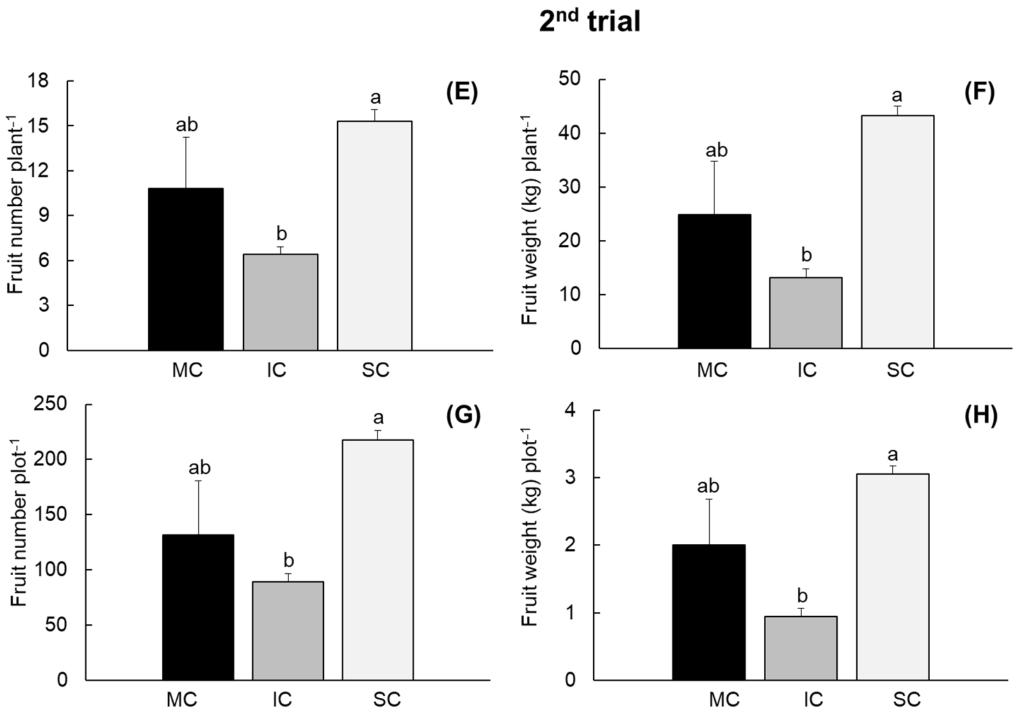

Figure 2. Effect of Salicornia-based crop management on tomato production in the first (April–June; (**A**–**D**)) and second (July–September; (**E**–**H**)) trial. (**A**,**E**) Fruit number per plant; (**B**,**F**) fruit weight (kg) per plant; (**C**,**G**) fruit number per plot; (**D**,**H**) fruit weight (kg) per plot. Different letters indicate statistically significant differences according to Duncan's multiple range test ($p < 0.05$). MC: monoculture, IC: intercropping, SC: sequential cropping with Salicornia.

3.2. Effect of Cultivation Method on Commercial Quality of Tomatoes

The cultivation method also influenced the commercial quality of red ripe tomatoes, but, in this case, the best performance was observed in fruits harvested from plants cultivated in consociation with Salicornia regardless of the trial considered, while no differences were observed between SC and control (MC) fruits (Table 2). Specifically, the IC fruits displayed the highest total soluble sugar content (TSSC) and titratable acidity (TA) (+48% and +46% in the first trial and +37% and +57% in the second trial, respectively, compared to control fruits). The cultivation system did not affect flesh firmness, pH, sugar–acid ratio (TSS/TA), and ripening index (RPI) in both trials.

Table 2. Commercial quality parameters of tomato fruits produced with different cultivation methods in the first (April–June) and second (July–September) trial. Values represent mean ± standard deviation, and, in each row, the values followed by different letters are significantly different according to Duncan's multiple range test (n = 12, $p < 0.05$). MC: monoculture, IC: intercropping, SC: sequential cropping with Salicornia.

		Cultivation Method		
		MC	**IC**	**SC**
1st trial	Flesh firmness (N)	3.82 ± 0.76 a	3.64 ± 0.83 a	4.18 ± 1.09 a
	pH	4.10 ± 0.06 a	3.97 ± 0.08 a	3.93 ± 0.06 a
	TSSC (% Brix)	4.33 ± 0.80 b	6.39 ± 1.62 a	4.18 ± 0.52 b
	TA (g citric acid g^{-1} fresh fruit)	0.26 ± 0.07 b	0.38 ± 0.10 a	0.25 ± 0.06 b
	TSSC/TA	16.90 ± 3.03 a	17.16 ± 2.31 a	17.26 ± 3.80 a
	RPI	3.11 ± 0.31 a	3.03 ± 0.36 a	3.18 ± 0.34 a
2nd trial	Flesh firmness (N)	2.13 ± 0.22 a	2.42 ± 0.14 a	1.96 ± 0.10 a
	pH	4.11 ± 0.04 a	3.97 ± 0.04 a	4.13 ± 0.04 a
	TSSC (% Brix)	4.40 ± 0.15 b	6.02 ± 0.66 a	4.35 ± 0.14 b

Table 2. *Cont.*

		Cultivation Method		
		MC	**IC**	**SC**
2nd trial	TA (g citric acid g^{-1} fresh fruit)	0.35 ± 0.04 b	0.56 ± 0.09 a	0.36 ± 0.01 b
	TSSC/TA	13.29 ± 3.85 a	11.51 ± 2.27 a	12.45 ± 0.43 a
	RPI	2.77 ± 0.20 a	3.03 ± 0.11 a	2.72 ± 0.09 a

3.3. Effect of Cultivation Method on Concentration of Phenolics and Flavonoids and Antioxidant Activity of Tomato Fruits

Significant variations in the TPC were induced by the cultivation method, with the highest values observed in IC fruits (+140% and +47% in the first and second trial, respectively, compared to MC), while SC tomatoes had an intermediate content (+90% and −21% compared to MC and IC in the first trial; +15% and −21% compared to MC and IC in the second trial; Figure 3A,D). The TFC was significantly higher (+75%) in IC tomatoes compared to MC ones (Figure 3B). Instead, no effect attributable to the cultivation system was evident for TFC in the second trial (Figure 3E).

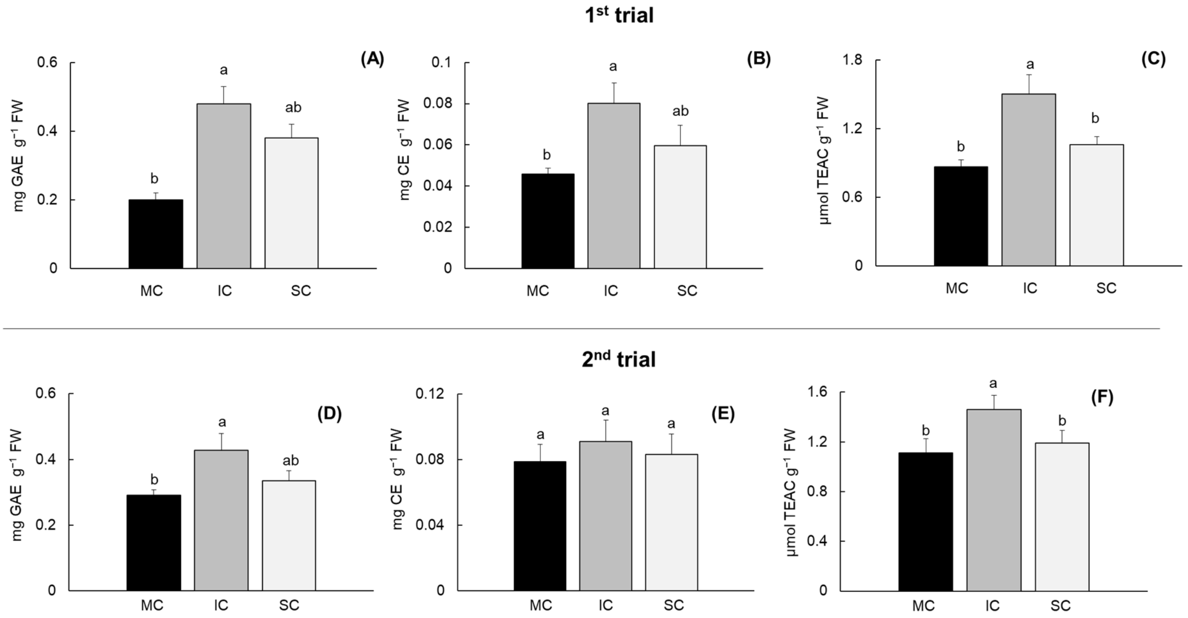

Figure 3. Effect of Salicornia-based crop management on total phenolic and flavonoid concentration and antioxidant capacity of tomato fruits in the first (April–June (**A**–**C**)) and second (July–September (**D**–**F**)) trial. (**A**,**D**) Total phenolic content (TPC) expressed as milligram of gallic acid equivalents per gram of fresh weight (mg GAE g^{-1} FW); (**B**,**E**) total flavonoid content (TFC) expressed as milligrams of catechin equivalents per gram of fresh weight (mg CE g^{-1} FW); (**C**,**F**) antioxidant capacity through ABTS assay expressed as micromoles of Trolox equivalent antioxidant capacity per gram of fresh weight (µmol TEAC g^{-1} FW). Different letters indicate statistically significant differences according to Duncan's multiple range test (n = 12, $p < 0.05$). MC: monoculture, IC: intercropping, SC: sequential cropping with Salicornia.

The antioxidant capacity of the phenol extracts assessed through the ABTS assay reflected the response of the TPC to the cultivation methods (Figure 3C,F). Specifically, the antioxidant potential of fruits harvested from IC plants was 73% and 42% higher than that of fruits collected from MC and SC plants in the first trial and 13% and 15% higher considering the second trial.

3.4. Effect of Cultivation Methods on the Carotenoid Profile and Content of Tomato Fruits

Table 3 shows the concentration of the main carotenoids of red ripe tomato fruits: β-carotene and lycopene, together with the two colorless precursors, phytoene and phytofluene. Except for β-carotene, which was unaffected by the cultivation system, all compounds were less concentrated in SC than in MC fruits (−32%, −60%, −16%, and −24% for phytoene, phytofluene, β-carotene, and lycopene in the first trial, respectively; −28%, −60%, −18%, and −33% for phytoene, phytofluene, β-carotene, and lycopene in the second trial, respectively). Interestingly, IC fruits exhibited an equivalent total carotenoid concentration to MC tomatoes, yet they showcased a greater lycopene concentration (+17% and +24% in the first and second trial, respectively) alongside reduced levels of phytoene and phytofluene (−26% and −19% in the first trial; −25% and −24% in the second trial, respectively).

Table 3. Carotenoid concentration (μg g^{-1} FW) of tomato fruits from different cultivation methods in the first (April–June) and second (July–September) trial. MC = monoculture; IC = intercropping; SC = sequential cropping with Salicornia. Values represent the mean ± standard deviation, and, in each row, the values followed by different letters are significantly different according to Duncan's multiple range test (n = 12, $p < 0.05$).

	Carotenoid	**Cultivation Method**		
		MC	**IC**	**SC**
1st trial	Phytoene	40.15 ± 3.21 a	29.69 ± 4.08 b	27.29 ± 1.87 b
	Phytofluene	22.57 ± 5.99 a	18.27 ± 3.86 b	9.01 ± 0.52 c
	β-carotene	20.54 ± 5.44 a	18.61 ± 4.42 a	17.23 ± 4.19 a
	Lycopene	89.14 ± 10.15 b	103.86 ± 13.12 a	67.81 ± 8.44 c
	Total	172.40 ± 12.62 a	170.43 ± 15.70 a	121.34 ± 9.40 b
2nd trial	Phytoene	32.77 ± 1.76 a	24.73 ± 5.38 b	23.61 ± 0.73 b
	Phytofluene	18.51 ± 3.92 a	14.11 ± 4.40 b	7.39 ± 0.67 c
	β-carotene	17.97 ± 4.49 a	14.83 ± 3.94 a	14.73 ± 3.68 a
	Lycopene	77.16 ± 13.18 b	95.98 ± 17.20 a	51.48 ± 4.88 c
	Total	145.47 ± 11.61 a	149.33 ± 23.07 a	97.54 ± 3.40 b

4. Discussion

This study was conducted within the framework of a research project focused on optimizing sustainable farming systems in moderately-to-highly saline soils. Indeed, the desalination abilities of halophyte species open up opportunities for the profitable cultivation of conventional crops in saline soils on one hand, while also offering the potential to utilize the biomass of the halophytes on the other [21,25]. The current study specifically investigated the yield and quality of tomato fruits grown in a greenhouse (soil EC and Na concentration, 1.66 ± 0.07 dS m^{-1} and 814 ± 19 mg kg^{-1}, respectively) using either IC or SC with Salicornia. Tomato, the predominant vegetable cultivated in the Mediterranean region [26], typically exhibits a slight, cultivar-dependent, susceptibility to salt stress.

Contrary to our expectations, tomato plants intercropped with Salicornia performed the worst among the three cultivation methods, achieving the lowest fruit yield, in both trials. These findings diverge from those of a comparable trial conducted in 2021, in which Salicornia and tomato plants were transplanted simultaneously (Supplementary Figure S2). In that trial, we observed approximately a 20% higher yield (both in terms of fruits number and weight per plant and per plot) in the IC treatment compared to the MC treatment. Given that, in the current experiment, the Salicornia plants were approximately one year older and significantly more developed than in the previous trial, it is likely that they established competition with the tomato plants. This suggests that Salicornia plants should be renewed every season, and their size must be controlled to maximize increases in tomato yield. Competition for nutrients by the halophyte purslane (*Portulaca oleracea* L.) and a consequent decrease in tomato yield has been reported by Qasam (1992) [27]. Similarly, Simpson et al. [28] detected the lowest yield of watermelon when consociated with purslane in an open field, while consociation with the garden orache (*Atriplex hortensis* L.) resulted in the highest yield. However, Zuccarini [29] reported that consociation with purslane gave the best results on tomato growth and yield in saline conditions, while the fast growth of *Salsola soda* caused nutritional competition with tomato, compromising the positive desalting effects provided by this species.

Nevertheless, the remarkable growth of Salicornia that occurred in one year of cultivation provided benefits to the tomato plants when cultivated in the SC system. Similar findings were reported by Jurado et al. [30], who observed no improvements in tomato yield with the adoption of mixed cultivation with *Arthrocaulon macrostachyum* L. in greenhouse conditions. However, they found that rotation was successful in achieving increased tomato productivity, underscoring the effectiveness of this crop management system.

The cultivation method also had an impact on the commercial quality of the red ripe tomatoes. However, this effect was contrary to that observed on fruit yield, since the highest levels of TSSC and TA were detected in the IC treatment, which is the one that resulted in the lowest yield. The negative relationship between fruit yield and quality (in terms of TSSC) was observed also in pepper (*Capsicum annuum*) fruits cultivated in consociation with *Salsola soda* [31], though these authors report increased yield and decreased quality, i.e., an effect opposite to ours. Jurado et al. [30] also observed a different influence of crop management on tomato yield and quality, with the latter being slightly reduced in SC plants characterized by the highest productivity. Interestingly, our results on the higher quality of IC tomatoes confirm those obtained the previous year (Supplementary Figure S3), despite the different yield performance between the two cultivation years. Therefore, the influence played by the consociation with Salicornia seems to be more complex than a mere impact on productivity. Indeed, based on the activity of certain antioxidant enzymes and the increased accumulation of superoxide radicals and hydrogen peroxide in the leaves of tomato plants grown in consociation or rotation with *A. macrostachyum*, Jurado et al. [30] propose that the presence of the halophyte may have induced a mild oxidative stress, subsequently triggering adaptation mechanisms. Although we did not specifically investigate the occurrence of oxidative stress in the tomato fruits, the highest concentration of phenolic compounds, which are typically produced in response to various stresses, was actually detected in IC fruits (Figure 3).

The different cropping strategies also reflected on the carotenoid accumulation, suggesting that IC could fasten the ripening process, as indicated by the higher lycopene accumulation accompanied by a lower concentration of its precursors, phytoene, phytofluene, and β-carotene (Table 3). Karakas et al. [32] found an increased lycopene content in tomato fruits when co-cultivated with *S. soda* or *P. oleracea*. They attributed this observation to the increased availability of energy and metabolic resources, as there was a reduced necessity to produce antioxidant/defensive compounds (e.g., ascorbic acid), due to the alleviation of salt-induced stress by the halophyte species. However, in our study, the consistent total carotenoid content between MC and IC fruits contradicts such an interpretation and instead suggests an acceleration of fruit metabolism. SC, on the other hand, led to a reduced accumulation of lycopene and total carotenoids, indicating that this cultivation system had a negative impact on carotenoid biosynthesis. This was further supported by the lowest content of their precursors.

5. Conclusions

In conclusion, our study demonstrated that introducing *Salicornia europaea* L. into moderately saline soils can provide benefits to tomato cultivation by increasing both tomato yield and quality, with the effectiveness depending on the choice of the cropping management system. Indeed, soil remediation achieved through one-year cultivation of Salicornia emerged as an effective strategy to boost tomato productivity in salt-affected soils without compromising fruit quality. This approach holds promise as a potential future strategy for enhancing crop productivity in Mediterranean regions. IC appears to be a particularly promising system for enhancing tomato quality. However, to ensure simultaneous increases in productivity, careful consideration should be given to using small-sized Salicornia plants to mitigate competition between species. Further research is needed to optimize the IC system and explore its long-term effects on soil health and overall agricultural sustainability. Moreover, due to the growing environmental issues of soil salinity and the loss of agricultural land, additional studies are necessary to validate our observations in soils with varying salt concentrations. In addition, the use of other halophyte plants with different desalting capacities might allow the cultivation of moderately-to-highly salt sensitive crops.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/horticulturae10060655/s1: Figure S1: Pictures of the experimental site where the trial was conducted. (A) The greenhouse, with the different plots corresponding to the different cultivation methods; (B) tomato plants in monoculture; (C) intercropping between tomato and Salicornia plants; (D) Salicornia plants in monoculture, which were replaced by tomato plants the second year of experimentation (sequential cropping); Figure S2: Effect of Salicornia-based crop management on the tomato production in the 2021 cultivation cycle. (A) Fruit number per plant; (B) fruit weight per plant; (C) fruit number per plot; (D) fruit weight per plot. Different letters indicate statistically significant differences according to Duncan's multiple range test (n = 12, $p < 0.05$). MC: monoculture, IC: intercropping; Figure S3: Effect of Salicornia-based crop management on the commercial quality in the 2021 cultivation cycle. (A) Flesh firmness (N); (B) total soluble solid content (TSSC; % Brix); (C) titratable acidity (TA; g citric acid g^{-1} FW). Different letters indicate statistically significant differences according to Duncan's multiple range test (n = 12, $p < 0.05$). MC: monoculture, IC: intercropping.

Author Contributions: Conceptualization, A.R. and A.C.; methodology, M.C.S., M.S. and A.C.; formal analysis, M.C.S. and M.S.; investigation, M.C.S. and M.S.; resources, A.R. and A.C.; data curation, P.P., M.S. and A.C.; writing—original draft preparation, P.P.; writing—review and editing, P.P., M.S. and A.C.; supervision, M.S. and A.C.; project administration, A.R. and A.C.; funding acquisition, A.R. and A.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The raw data used in this study are available upon reasonable request due to ongoing research.

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

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