Research Article

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Cost–benefit analysis of tomato in soilless culture systems with saline water under greenhouse conditions

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Abstract

BACKGROUND: The current need to produce food for a growing population, from diminishing natural resources, such as water and energy, and with minimum environmental degradation, demands the optimization of production. We compare the economic feasibility of tomato production in an open system with a perlite substrate, a closed system with the nutrient film technique (NFT), and a hydroponic crop (deep flow technique, DFT) using three levels of salinity that are found within the normal range for irrigation water quality in southeastern Spain.

RESULTS: Production with DFT resulted in an increase in the cost of phytosanitary treatments and the cost of maintenance. Production with perlite resulted in an increase in the cost of irrigation water and fertilization, and the use of NFT resulted in an increase in energy costs. The point of price equilibrium was exceeded in the three soilless systems when using low salinity water, and in perlite, with intermediate salinity water.

CONCLUSION: Profitability was reduced in the following order: perlite > NFT > DFT. There were positive results when using irrigation water with low salinity, and in the case of perlite, with intermediate salinity. In every case, salinity reduced the profitability of the operation, and this was greater when NFT was employed. The analysis of these soilless systems should be continued to determine the possibility of reducing cultivation costs.

Keywords: costs; production; income; benefits; break-even point

INTRODUCTION

In the next few years, it will be necessary to produce enough food for a growing population, with decreasing natural resources per inhabitant, and causing minimum environmental degradation.[1] Greenhouse cultivation is the most intensive manner of production.[2] Worldwide, the most important crop is the tomato, with Almeria (Spain) being the leading producer area of fresh tomato in Europe.[3] There is a wide gamut of tomato production systems in greenhouses. Although tomato cultivation in greenhouses has been conducted mainly in soil, the use of other substrates, notably perlite, has shown adequate results. The Euphoros consortium (2013) studied the economic viability of various innovations on tomato production in greenhouses in different European scenarios (Spain and the Netherlands), concluding that a closed irrigation system with a perlite substrate could be economically viable in Almeria, Spain.

Among the different hydroponic growing systems, the nutrient film technique (NFT)[4] is notable. At first, its use implied a high initial investment compared to other substrate systems. Subsequently, more affordable NFT systems were developed.[5,6] Recently, a new type of NFT system, called the New Growing System (NGS, Almeria, Spain), started to be commercialized. The manufacturer of this new system has optimized its management to produce tomatoes with water savings, resulting in a mature and competitive technology.

Southeastern Spain has an arid and semiarid climate with scarce water resources, which are usually of low quality – the electrical conductivity (EC) in the subterranean aquifer of the hydrographic basin of the Segura river can reach values of 8.0 dS m^{-1}).[7] The high water demand of the crops – which, globally, accounts for 85% of water demands in arid and semiarid regions with highly technical agriculture, such as southeastern Spain[8] – and the fragility of the ecosystems in the area compromise the viability of these

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operations. It is important to pay special attention to the economic results of the exploitation of resources and the care of the environment. There are numerous studies on the response of the tomato to salinity using different soilless culture systems.[9] However, comparative economic studies have not been conducted on the production of tomatoes using different soilless culture systems. The objective of this work was to establish and compare the economic viability of tomato production in greenhouses with three soilless culture systems – an open system with a perlite substrate, a closed system with NFT, and a closed system of hydroponic crop, the deep flow technique (DFT) – using irrigation water of varying quality. The quality of irrigation water was modified with the addition of NaCl, changing the value of the EC of irrigation water within the usual range found in the southeast of Spain.

MATERIALS AND METHODS

Plant material and growing conditions

The experiments were conducted between April and July in two consecutive years with tomato plants (*Solanum lycopersicum*, L.), variety 'Optima' (Baby Plant, Murcia, Spain). The greenhouse used was located in the experimental station of Santomera (Murcia, Spain), located at coordinates 38° 6′ 26″ N and 1° 2′7″ W. A multi-tunnel greenhouse with a covered area measuring 650 m^2 was used, with a height of 4.5 until the tunnel. It had a lateral enclosure and cover made of polycarbonate. The climate control of the greenhouse was made possible with an indirect combustion hot-air generator (SIAL Mirage 65, Munters, Chiusavecchia, Genoa, Italy), fans, side and ceiling ventilation, and a cooling system (Novedades Agrícolas, Murcia, Spain), shade netting (Aluminet 30%, Novedades Agrícolas, Murcia, Spain), and a humidifier setup (Ingersoll Rand SSR, Dublin, Ireland). The temperature and relative humidity values in the interior of the greenhouse were periodically recorded through sensors place at a height of 1.5 m. The mean values for the experiment were 381 $W{\cdot}m^{-2}$, 24 °C, and 66%, respectively. The growing techniques employed were similar to those used in commercial greenhouses in the area. For the control of pests (*Myzus persicae, Frankliniella occidentalis,* and *Bemisia tabaci*), Confidor 20 (imidacloprid 20% p/v) and Applaud 25 (buprofezin 25% p/p) were used.

Three soilless culture systems were utilized: DFT, with a density of 1.9 plants m^{-2}; perlite, with 2.5 plants m^{-2}; and NFT, with 2.5 plants m^{-2}. The nutrient solution (NS) for the irrigation was the same for all three growing systems, and was composed of 6 mM KNO_3, 4 mM $Ca(NO_3)_2$, 1 mM KH_2PO_4, 1 mM $MgSO_4$, 20 μM Fe^{+3} masquolate, 25 μM H_3BO_3, 2 μM $MnSO_4$, 2 μM $ZnSO_4$, 0.5 μM $CuSO_4$ and 0.5 μM. $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$, with pH = 6.0. Two weeks after transplanting, the plants from each growing system were divided into three groups, to which the following salt treatments were applied: control (S0; EC = 2.2 dS m^{-1}), 40 mM NaCl (S1; EC = 6.3 dS m^{-1}), and 80 mM NaCl (S2; EC = 10.2 dS m^{-1}). To avoid a possible osmotic shock, the S1 and S2 salt treatments were started with a concentration of 20 mM NaCl, which was increased by 20 mM per day until the final concentration needed was reached.

The DFT growing system was conducted with 120 L polyvinyl buckets, with continuous aeration. The buckets were covered with a black plastic cover where the plant was held (Fig. 1(A)). The volume of the NS was verified three times a week, and was maintained constant by adding distilled water. The NS nutrients and the pH were analyzed weekly to reset the initial values by adding nutrients and NaOH, respectively. In the perlite growing system, 40 L (1.20 × 0.22 × 0.15 m^3) sacs were used, with three plants each (Fig. 1(B)). The management of irrigation was conducted in agreement with the normal recommendations for the area for tomato in perlite.[10] Self-compensating and self-draining drippers were used, with an irrigation rate of 3.0 L h^{-1}, and a weekly program was used, taking into account the volume of drainage and the EC. The drainage water volume was 15% of the volume applied in the initial irrigation, and the volume applied in the initial watering was increased by 5% for every 1.0 dS m^{-1} increase of the EC of the drainage water, to a maximum of 30% to avoid excessive consumption of water. The NFT growing system used multi-bands shaped as a V – a system named the New Growing System (NGS©) – with 12 plants per line (Fig. 1(C)). The drainage solution was stored in a 1000 L tank, to be recirculated later in the closed system. Self-compensating and self-draining drippers with a rate of 8.0 L h^{-1} were utilized. The EC of the solution in the tank was monitored daily by adding distilled water. The nutrients and the pH were monitored weekly, and were reset when needed. During the first 30 days after transplanting, the plants were watered for 5 min, and the irrigation was stopped in the next 15 min. Afterwards, the interval without irrigation was reduced to 10 min, and lastly to 5 min. The mean values of the volume of the NS utilized in treatments S0, S1, and S2 were, for DFT, 344, 314, and 251 L m^{-2}, for NFT, 440, 420, and 410 L m^{-2}, and for perlite, 488, 430 and 380 L m^{-2}, respectively.

The total fruit yield (kg m^{-2}) was determined by harvesting the tomatoes daily during the experiment, between weeks 24 and 31, determining their fresh weight and caliber individually. According to these values, the fruits were classified as marketable or non-marketable (fresh weight < 70 g, with apical rotting, cracking, or some type of deformation or mechanical damage).

Economic analysis

The cost–benefit analysis determines if the revenue created by an investment project exceeds its costs. A structure of costs and revenue for a representative exploitation of the crop in

Figure 1. Soilless culture systems used in this experimental study: deep flow technique (A), perlite (B), and nutrient film technique (C).

southeastern Spain was utilized.[11] The costs and income are the means of two years of the assay, so they represent an average year.

The costs were classified into fixed and variable costs. The fixed costs did not depend on production, whereas the variable costs, among which harvesting costs are highlighted, do have a direct relationship with the final production. The fixed costs are classified into overhead costs and operational fixed costs. The overhead costs are projected as a multi-year cost (structure installation and greenhouse cover installation, irrigation systems, etc.), and are introduced in the annual computation through amortizations, through a linear method or constant installments, assuming that they will only be used during the length of the experiment. The fixed operational costs did not depend directly on the final production, such as, for example, the irrigation water, the fertilization, pesticides, etc. The cost of the machines refers to the amount paid to third parties for providing a service. To calculate the employment created, an average salary cost of 14 250 € year^{-1} was established (which included salary and social security), considering 1840 annual hours of work[12] as the unit of agricultural work. The cost was separated into social security and salary, with the latter applied to the activity performed (planting, irrigation, plant staking / training, etc.). Within the operational cost variables, only the harvesting labor was taken into account, as it was the only cost that was dependent on production. The opportunity cost is considered to be the benefits that are no longer gained by the investor due to the investment in this project, instead of investing in public debt without risk. An interest rate of 2% was used, in line with the profitability of the 10-year government bonds.[13]

The revenue was obtained from weekly production and the official prices for the market[14] between 2005 and 2014. Given that no official prices as a function of caliber exist, the prices provided by the main agricultural cooperatives of the area were used (2016 and 2017) to obtain the average prices per caliber for the season. This information allowed us to obtain the price index for each caliber with respect to the average price.

The revenue was obtained as the difference between the total income and total costs. The following were also estimated: the total revenue / cost ratio, the average sale price (ratio between income and unit production), the break-even point (average price of the harvest that allows the grower to cover total costs in a cropping cycle), the distance to the break-even price (differences between both prices), the break-even point of production (average production needed so that the revenue equal the total costs), and the distance to the break-even production (difference between the production obtained and the production required to avoid losses).

Statistical analysis

A four-way analysis of variance (ANOVA) (soilless culture system × salinity × block × time) was performed with the data from the experiment. The block and time effects were not significant ($P > 0.05$), so only the results of a two-way ANOVA, with the soilless culture system and salt treatment as the main factors, are reported. The statistical package used was SPSS (Chicago IL, USA). When this interaction was significant ($P < 0.05$), the treatment means were separated by Tukey's honestly significant difference (HSD) multiple-range test, using lowercase letters to indicate significant differences between salt treatments for each soilless culture system, and uppercase letters to indicate significant differences between soilless culture systems for each salt treatment.

RESULTS AND DISCUSSION

Production and quality

The soilless cultivation system and the salt treatment had an influence on commercial production, although the interaction between these factors was not significant. For perlite, the average value of commercial production was 7.84 kg m^{-2}, and decreased by 9%, and 25% when utilizing the DFT and the NFT, respectively. The effect of the salt treatment was greater, as in control conditions (S0 level), the average commercial production value was 9.90 kg m^{-2}, being reduced by 32% at the S1 salt level, and 57% for treatment S2. In control conditions, the commercial production was very similar in the three soilless culture systems (Fig. 2(A)).

The aerial biomass of the tomato plants varied depending on the soilless culture system and salt treatment, and the interactions of both factors were very significant. In the DFT system, the average value for the aerial biomass was 5.24 kg m^{-2}, and decreased by 29% in perlite and 41% in NFT. The effect of the salt treatment was weaker as the aerial biomass of the control (4.27 kg m^{-2}) was reduced by 4% in treatment S1 and 14% in salt level S2. The smallest value of aerial biomass was found in the plants grown with the NFT subjected to salt level S2 (Fig. 2(B)).

The commercial unit production (kg fresh fruit kg^{-1} aerial biomass) varied depending on the soilless culture system and salt treatment. The interaction of both factors was not significant. The tomato plants grown in perlite had a commercial unit production of 2.1 kg kg^{-1}, and it was reduced by 13% in NFT and 33% in DFT. The effect of the salt treatment was greater, so that the commercial unit production in the control group (2.3 kg kg^{-1}) decreased by 27% in the S1 treatment, and by 48% in the S2 one. In control conditions, the average values were 2.6, 2.5 and 2.0 kg kg^{-1} in perlite, NFT, and DFT, respectively (Fig. 2(C)).

The water-use efficiency (WUE) varied depending on the soilless culture system and the salt treatment in a highly significant manner, although the interaction of both factors was not significant. The average value of the WUE for DFT was 23.5 kg m^{-3}, and was reduced by 24% in perlite and 41% in NFT. The effect of the salt treatment was similar. The average value of the WUE in control plants was 23.9 kg m^{-3} and was reduced by 25% in the S1 treatment and by 45% in the S2 one. The smallest WUE value was found in plants cultivated in NFT with treatment S2. In control conditions, the average WUE values were 28.2, 22.0, and 21.5 kg m^{-3} in DFT, NFT, and perlite, respectively (Fig. 2(D)).

The WUE values in the production of tomato varied due to numerous factors (open air or greenhouse cultivation, variety, cropping cycle, growing system used, composition of the nutrient solution, management of irrigation, etc.). In numerous studies, values that oscillated between 26.0 and 17.0 kg m^{-3} in different conditions have been found.[15–20] In this experiment, commercial unit production values lower than 0.55 kg kg^{-1} were found, probably due to the characteristics of the tomato plant used (cherry tomato). The plants grown with the DFT system were larger and more productive, even in conditions of high salinity.[21] However, the commercial unit production was smaller, due to the low density of the plantation. Its WUE was greater due to its lower consumption of nutrient solution. The plants cultivated in perlite and NFT in control conditions showed similar behavior. The decrease in growth and commercial production due to salinity were greater in plants grown in NFT, probably due to the progressive concentration of salts throughout the NFT growing cycle.

Salinity treatment improved the quality of the fruits by increasing the total soluble solids and titratable acidity, particularly in

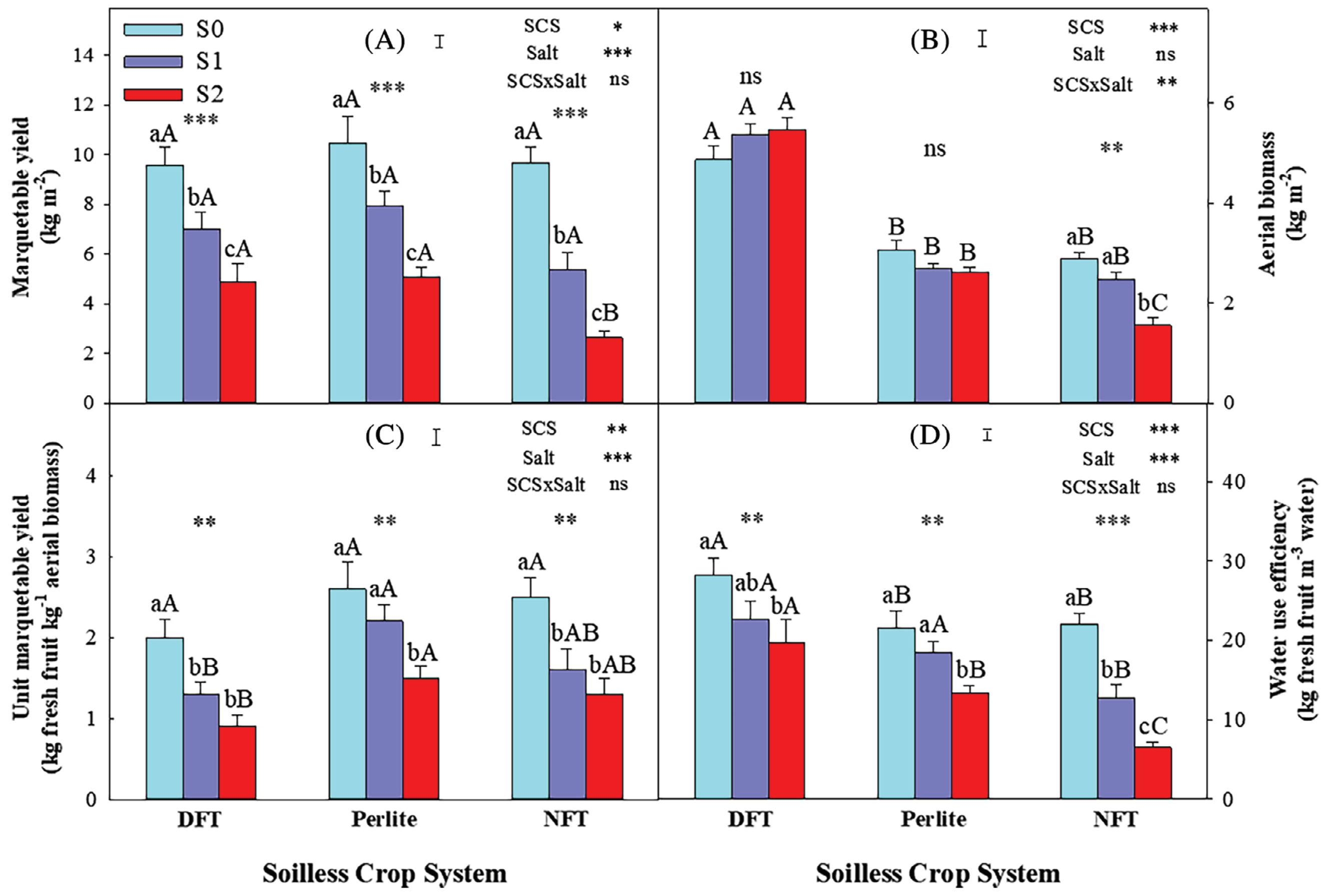

Figure 2. Marketable yield (kg m^{-2}), aerial biomass (kg m^{-2}), unit marketable yield (kg kg^{-1}) and water use efficiency (kg m^{-3}) of tomato plants grown in three soilless culture systems and three salt treatments. The error bar indicates the standard error of the mean (n = 16–48). ***, and 'ns' indicate significant differences at $P < 0.001$, and non-significant differences, respectively. Values with different letters differ significantly at the 95% level, according to Tukey's HSD test. Lowercase letters compare salinity treatments for each soilless culture system. Uppercase letters compare soilless culture systems for each salinity treatment.

Table 1. Overhead costs

	Price	Useful life (years)	Months in use year^{-1}	Depreciation	Opportunity cost	Total cost
Structure (€ m^{-2})	6.00	30	4	0.07	2%	0.07
Polypropylene side enclosure (€ m^{-2})	0.20	3	4	0.02	2%	0.02
Polypropylene Anti-thrip netting 10 × 20 m (€ m^{-2})	0.06	3	4	0.01	2%	0.01
Polypropylene roof/ceiling (€ m^{-2})	0.70	3	4	0.08	2%	0.08
Assembly (€ m^{-2})	3.50	30	4	0.04	2%	0.04
Total	10.46			0.21		0.22

the NFT system.[21] However, this improvement in quality was not accompanied by an increase in the price (see below).

Economic results

Costs

The overhead costs were the same for every growing system and the salt treatments used. These have been divided into structure and construction, and enclosures and protection netting. The useful life was considered to be 30 years for the structure and its construction.[22] The total cost of building a greenhouse is 10.46 € m^{-2} (Table 1).

Various works have shown the cost of the greenhouse structure, such as Hickman,[23] who calculated a cost of 46.44 € m^{-2}, Jensen and Malter[24] who estimated the cost of a modern greenhouse, exclusive of land, at 80.39–89.32 € m^{-2}, when the soilless culture system was included. In the Netherlands, the cost of a modern greenhouse, exclusive of land but including total climate control, transport, and fertilization, is about 67.00 € m^{-2}.[25] The difference between these values and the value determined in this work is due to the installations considered in the estimation of the cost (climate control, irrigation, growing systems, etc.).

The fixed operational costs were divided into the costs of raw materials, labor, and other fixed costs (Table 2). In southeastern Spain, the structural scarcity of water makes it a limiting factor for agricultural production. The price and the quality of the irrigation water varied considerably. The price of the good-quality

Table 2. Fixed operational costs, variable operational costs, opportunity costs, overhead costs, and total costs (€ m^{-2})

	DFT			Perlite			NFT		
	S0	S1	S2	S0	S1	S2	S0	S1	S2
FIXED OPERATIONAL COSTS(€ m^{-2})	**4.26**	**4.21**	**4.06**	**3.46**	**3.30**	**3.19**	**3.68**	**3.55**	**3.35**
RAW MATERIALS (€ m^{-2})	**0.94**	**0.88**	**0.77**	**1.07**	**0.94**	**0.85**	**1.04**	**0.96**	**0.84**
Irrigation water (€ m^{-2})	0.11	0.07	0.02	0.16	0.09	0.04	0.15	0.09	0.04
Plants (€ m^{-2})	0.19	0.19	0.19	0.25	0.25	0.25	0.25	0.25	0.25
Pesticides (€ m^{-2})	0.28	0.30	0.27	0.15	0.14	0.14	0.15	0.14	0.08
Colored traps (€ m^{-2})	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Pollination (€ m^{-2})	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Electricity (€ m^{-2})	0.03	0.03	0.03	0.07	0.06	0.06	0.10	0.09	0.09
Fertilization (€ m^{-2})	0.23	0.21	0.17	0.34	0.30	0.27	0.30	0.29	0.28
Polypropylene thread and training rings (€ m^{-2})	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
LABOR (€ m^{-2})	**2.13**	**2.13**	**2.08**	**1.44**	**1.41**	**1.40**	**1.54**	**1.50**	**1.41**
Preparation and planting (€ m^{-2})	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Irrigation and fertilization (€ m^{-2})	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05
Plant training (€ m^{-2})	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Phytosanitary treatments (€ m^{-2})	0.40	0.42	0.39	0.21	0.20	0.20	0.21	0.19	0.11
Shading (€ m^{-2})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant care tasks (pruning, *etc.*) (€ m^{-2})	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Cleaning, maintenance and repairs (€ m^{-2})	0.70	0.70	0.70	0.30	0.30	0.30	0.40	0.40	0.40
Social security of the laborers (€ m^{-2})	0.22	0.20	0.19	0.17	0.15	0.14	0.17	0.15	0.14
Social security (owner) (€ m^{-2})	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
OTHER FIXED COSTS (€ m^{-2})	**1.20**	**1.20**	**1.20**	**0.95**	**0.95**	**0.95**	**1.09**	**1.09**	**1.09**
Machinery (€ m^{-2})	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Hydroponic system (€ m^{-2})	0.30	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00
Soilless culture system (substrate, trays, *etc.*) (€ m^{-2})	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00
Multi-band NFT system (€ m^{-2})	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02
NFT supports and trellises NFT (€ m^{-2})	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.11
Installation of irrigation (€ m^{-2})	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06
Leasing of land (€ m^{-2})	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Taxes and administrative tasks (€ m^{-2})	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
VARIABLE OPERATIONAL COSTS (€ m^{-2})	**1.02**	**0.75**	**0.52**	**1.12**	**0.85**	**0.55**	**1.03**	**0.57**	**0.28**
Labor for harvesting (€ m^{-2})	1.02	0.75	0.52	1.12	0.85	0.55	1.03	0.57	0.28
OPPORTUNITY COSTS (€ m^{-2})	**0.11**	**0.10**	**0.09**	**0.09**	**0.08**	**0.07**	**0.09**	**0.08**	**0.07**
TOTAL OPERATIONAL COSTS (€ m^{-2})	**5.39**	**5.06**	**4.67**	**4.67**	**4.24**	**3.81**	**4.81**	**4.21**	**3.70**
OVERHEAD COSTS (€ m^{-2})	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
TOTAL COSTS (€ m^{-2})	**5.61**	**5.28**	**4.89**	**4.89**	**4.45**	**4.03**	**5.02**	**4.42**	**3.92**

water of the Tajo-Segura transfer system is usually 0.11 € m^{-3}.[26] The price of water from subterranean aquifers (high EC values, generally) varies depending on the energy needed to extract it. Groundwater and desalinated water (low EC values), with a cost of more than 0.33 € m^{-3}, is frequently used to compensate for the supply deficit.[27] Many irrigation communities in the region have reported prices between 0.15 and 0.47 € m^{-3} (personal communication). Given the characteristics of the experimental design used in the present work, and considering that the improvement of the quality of water implies an increase in its cost, a price of 0.33 € m^{-3} has been established for the cost of salt level S0, 0.10 € m^{-3} for S2 and an intermediate cost for S1. However, in practice, it is not common for the operation to have water from two different sources available, due to the infrastructure required for its distribution, which would hinder the grower from choosing the characteristics of the irrigation water.

Some of these raw materials have a constant cost, with others having a variable cost. Thus, the cost of fertilization is dependent on the consumption of the NS; the price of the pesticides increases as the plant's biomass increases, and the price of energy depends on the soilless growing system utilized. The cost of the raw materials is higher for perlite, followed by NFT and DFT. With respect to the salt treatments, S0 incurred the greatest costs, followed by S1 and S2. The most important items of this section were irrigation water, plants, fertilizers, and pesticides. In particular, for perlite, the costs of irrigation water oscillated between 0.04 and 0.16 € m^{-2}, while for DFT the range was from 0.02 to 0.11 € m^{-2}. Fertilizer costs were greater for perlite (between 0.27 and 0.34 € m^{-2}). The pesticides were the only item whose costs in the DFT were higher than the rest. Finally, the energy consumption was higher than 0.09 € m^{-2} in the three NFT treatments, whereas the lowest values were found in DFT.

As for labor, the greater costs were found for the DFT. The salt treatments barely had an influence on the results. The more important items were related to cleaning, maintenance, and repairs, which were dependent on the type of soilless growing system considered, followed by phytosanitary treatments, which increased along with the plant's biomass, and tasks related to preparation and planting, which were found to be constant.

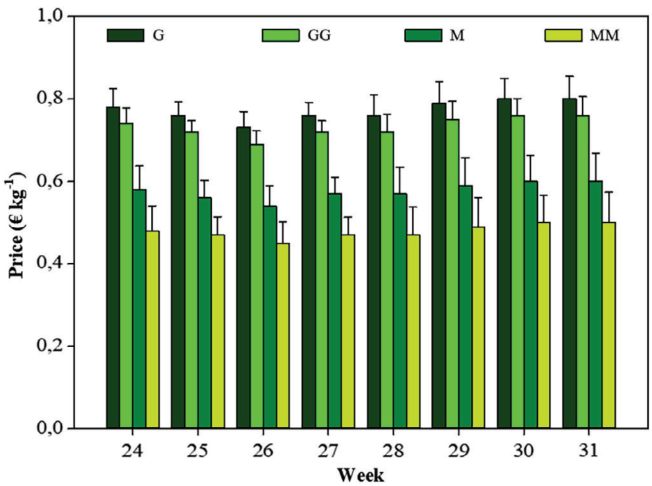

Figure 3. Changes in the average weekly prices as a function of caliber (D: diameter). MM: (47 < D ≤ 56) mm; M: (57 < D ≤ 66) mm; G: (67 < D ≤ 81) mm; GG: (82 < D ≤ 101) mm.

As for the fixed costs, the results varied as a function of the system's own characteristics, being higher in the DFT, followed by the NFT and perlite (Table 2). The variable operational costs were higher for the perlite system (between 0.55 and 1.12 € m^{-2}), followed by DFT (between 0.52 and 1.02 € m^{-2}), and with the lower costs corresponding to the NFT (between 0.28 and 1.03 € m^{-2}) due to the production of a smaller amount. With respect to the salt treatments, the costs for the control (S0) were higher than the rest of the salt treatments.

The cost structure is similar to that of other works, such as Lopez-Marín *et al.*[11] although, instead of the depreciation cost, Lopez-Marín *et al.* uses the net present value methodology. Calatrava and Villa[28] conducted an economic study on the production of tomato in greenhouses in Almeria, concluding that the consumption of water and fertilizers was inefficient from the economic point of view. They did not find a correlation between the consumption of water and fertilizers and the revenue obtained. This could be due to the growers preferring to fertigate more than necessary, thinking that doing otherwise could negatively impact quality and production. It could also due to the inflexibility of irrigating with nutrient solution.

Revenue

Weekly prices per caliber were obtained, starting with the price index of each caliber. The prices of caliber G were slightly higher than those of caliber GG, with caliber MM having the lowest prices (Fig. 3). The weekly prices were very stable, although they were slightly higher between weeks 29 and 31 (the last two weeks of July and the first week of August).

Table 3 shows the average values of the weekly production related to caliber for each soilless culture system as a function of the salt treatment. Approximately, the production is one week ahead for NFT. However, the revenue does not vary due to the price is relatively constant through the growing cycle. The greatest production was found for perlite, and in all the cases it decreased as the concentration of salts in the nutrient solution increased. As for the distribution of calibers, the predominant one was GG in the NFT and perlite systems, totaling more than 90% of the total production, whereas, for the DFT system, the G caliber encompassed more than 50%. The most important weekly production was found to occur in the last weeks of the growing cycle (July). It is apparently difficult to explain the choice of a short cycle and the elimination of a crop when production is still high. However, this choice is justified by the change in prices and the increase in the production costs as the growing cycle is lengthened. A second short cycle, initiated at the end of the cycle analyzed in the present work, could imply a reduction of the cultivation costs, and its production occurs when the mean value of the price exceeds the prices during the harvest part in the first growing cycle analyzed in the present work by 20% (data not shown). This type of strategy allows the growers to increase their profit and perhaps to reduce their production costs in comparison with a long production cycle.

Table 4 shows the average value of the weekly revenue accumulated by the soilless systems as a function of the quality of the irrigation water. The greatest revenues were produced in perlite, followed by NFT and DFT. With respect to the salt treatments, S0 represented values higher than S1 and S2 in all the cases. As with production, the revenue was higher in the last weeks of the growing cycle (July).

Economic indicators

The production of tomato resulted in revenues for all the soilless culture systems in control conditions (S0), decreasing in the order of perlite, NFT and DFT (3.19 € m^{-2}, 2.56 € m^{-2}, and 1.58 € m^{-2}, respectively). Cultivation in perlite also produced revenues in the S1 treatment (1.55 € m^{-2}). The revenues for perlite and NFT were due to the greater incomes as well as lower operational costs.

The profit / total cost ratio was positive in control conditions, decreasing in value following the order perlite, NFT, and DFT (0.64, 0.52 and 0.29, respectively). It was also positive in perlite for treatment S1 (0.35) (Table 5).

The results were consistent with those from other studies such as Zhai *et al.*,[29] whose 3-year study on the effects of saline water irrigation on tomato yield, quality, and blossom-end rot was conducted with different salinity levels, showing that yield decreased with increased salinity. In the same way, an economic analysis indicated that the EC threshold value above which the value of fruit production decreased linearly with increasing salinity was 3.3 dS m^{-1}, which was the same as that for marketable yield.[30]

In control conditions (S0), the three soilless culture systems resulted in revenue, and the average selling price was higher than the break-even point, with the difference decreasing in the order of perlite, NFT, and DFT (0.31, 0.25 y 0.16 € kg^{-1}, respectively). In the S1 treatment, the average price was 0.20 € kg^{-1} above the break-even point for perlite. However, for NFT and DFT, the average prices would have to increase 0.09 and 0.05 € kg^{-1} to reach equilibrium. It is possible that this occurs in some years due to the high volatility of the prices. Finally, so that the S2 treatment reaches equilibrium, the prices would have had to increase by 0.05, 0.83, and 0.34 € kg^{-1} for perlite, NFT, and DFT, respectively. To explain these results, it is important to note that, for example, in NFT with the S2 treatment, there is a high percentage of low-caliber fruit (20% between M and MM) and low production, which revolves around a fourth of the production from the S0 treatment. On the other hand, there is a reduction in the variable costs, although it does not compensate for the lower profits. Except for perlite, therefore, it would be difficult to find years where the equilibrium was reached.

Figure 4(A) shows the minimum production needed to cover the total costs of production. The equilibrium point is greater in DFT (for all the salt levels) due to higher fixed costs, greater than 4.00 € m^2, and is lower in perlite, varying between 3.47 and 3.74 € m^2.

Table 3. Changes in the average value of the weekly aggregated production per caliber for each soilless culture system as a function of the salt treatment. Mean values ± standard deviation. Values with different letters differ significantly at the 95% level, according to Tukey's HSD test. Uppercase letters compare soilless culture systems for each salinity treatment. Lowercase letters compare salinity treatments for each soilless culture system

		S0 (kg m^{-2})					S1 (kg m^{-2})					S2 (kg m^{-2})				
	Week	G	GG	M	MM	Total	G	GG	M	MM	Total	G	GG	M	MM	Total
DFT		–	–	–	–	0 ± 0C	–	–	–	–	0 ± 0C	–	–	–	–	0 ± 0B
	25	0.31 ± 0.11	–	0.10 ± 0.02	–	0.40 ± 0.13a	–	–	–	–	0 ± 0Cc	0.092 ± 0.027	–	–	0.04 ± 0.01	0.13 ± 0.02Bb
	26	–	–	0.04 ± 0.02	0.01 ± 0.01	0.05 ± 0.13B	0.06 ± 0.00	–	0.13 ± 0.04	–	0.19 ± 0.05C	–	–	1.03 ± 0.01	–	0.10 ± 0.02B
	27	4.03 ± 57	1.58 ± 60	0.08 ± 0.00	–	0.64 ± 0.11C	2.86 ± 999	–	1.72 ± 25	–	0.46 ± 0.12B	0.225 ± 0.082	–	0.12 ± 0.05	0.06 ± 0.03	0.40 ± 0.10B
	28	0.69 ± 0.26	1.01 ± 0.26	0.22 ± 0.02	–	1.93 ± 0.54a	4.91 ± 1.694	1.22 ± 52	2.61 ± 98	0.03 ± 0.10	0.90 ± 0.26b	0.570 ± 0.082	0.47 ± 0.13	0.17 ± 0.09	0.06 ± 0.04	1.26 ± 0.26Ab
	29	1.23 ± 0.77	0.65 ± 0.48	0.12 ± 0.03	–	2.01 ± 1.28a	0.35 ± 0.150	0.42 ± 0.096	0.17 ± 0.05	0.046 ± 0.00	0.98 ± 0.10a	0.342 ± 0.067	–	0.23 ± 0.08	0.12 ± 0.07	0.69 ± 0.05Ab
	30	0.64 ± 0.98	0.66 ± 0.66	0.13 ± 0.03	–	1.44 ± 1.68	1.30 ± 0.182	0.48 ± 0.012	0.38 ± 0.07	0.036 ± 0.01	2.20 ± 0.10A	0.865 ± 0.055	–	0.38 ± 0.03	0.18 ± 0.05	1.42 ± 0.20A
	31	1.97 ± 1.10	0.62 ± 0.43	0.60 ± 0.19	–	3.19 ± 1.62ABa	1.32 ± 0.014	0.14 ± 0.009	0.69 ± 0.22	0.119 ± 0.02	2.27 ± 0.19Aa	0.000 ± 0.055	0.309 ± 0.12	0.25 ± 0.13	0.30 ± 0.10	0.86 ± 0.15Bb
	Total	5.24 ± 1.10Aa	3.10 ± 0.43Ca	1.30 ± 0.09Ab	0.01 ± 0.01Cc	96.56 ± 16.22ABa	3.818 ± 0.014Cc	1.16 ± 0.085Cb	1.81 ± 0.22Aa	0.231 ± 0.02Ab	7.01 ± 0.19Ab	2.094 ± 0.055Ab	0.781 ± 0.12Cc	1.25 ± 0.13Ab	0.75 ± 0.100Aa	4.87 ± 0.15Ac
Perlite	24	–	0.01 ± 0.00	–	–	0.01 ± 0.00Bb	–	0.02 ± 12	0 ± 0	–	0.02 ± 0.00Ba	–	–	–	–	0 ± 0Bc
	25	–	0.26 ± 0.10	–	–	0.26 ± 0.10	–	0.16 ± 407	0.01 ± 27	–	0.17 ± 0.04B	0.03 ± 0.01	0.21 ± 0.05	0.01 ± 0.00	–	0.25 ± 0.05A
	26	0.03 ± 0.01	0.42 ± 0.10	0.01 ± 0.00	0.01 ± 0.00	0.47 ± 0.10A	0.07 ± 58	0.32 ± 0.167	0.03 ± 0.01	0.025 ± 0.01	0.44 ± 0.16B	0.05 ± 0.01	0.33 ± 0.11	0.04 ± 0.01	0.05 ± 0.01	0.48 ± 0.10A
	27	0.03 ± 0.01	0.92 ± 0.01	0.02 ± 0.00	0.02 ± 0.01	0.99 ± 0.01Ba	0.05 ± 0.018	0.65 ± 0.103	0.03 ± 0.01	0.029 ± 0.00	0.76 ± 0.11Ab	0.04 ± 0.01	0.54 ± 0.10	0.03 ± 0.01	0.02 ± 0.00	0.64 ± 0.11Ab
	28	0.01 ± 0.02	1.63 ± 0.47	0.01 ± 0.01	–	1.65 ± 0.48a	0.02 ± 0.025	1.26 ± 0.424	0.01 ± 0.02	0.012 ± 0.00	1.31 ± 0.43a	0.05 ± 0.01	0.76 ± 0.02	0.01 ± 0.02	0.03 ± 0.01	0.85 ± 0.03Bb
	29	0.01 ± 0.02	1.81 ± 0.83	–	–	1.82 ± 0.84a	0.03 ± 0.034	1.16 ± 0.244	0.01 ± 0.02	0.017 ± 0.00	1.21 ± 0.26a	0.02 ± 0.00	0.61 ± 0.09	–	0.01 ± 0.01	0.64 ± 0.06Ab
	30	0.01 ± 0.01	1.21 ± 0.98	–	–	12.23 ± 9.90	0.03 ± 0.041	0.58 ± 0.418	–	–	0.62 ± 0.44B	0.06 ± 0.02	0.060 ± 0.07	0.02 ± 0.01	0.01 ± 0.01	0.69 ± 0.07B
	31	1.58 ± 11	3.75 ± 0.08	0.10 ± 0.04	0.04 ± 0.01	40.39 ± 19Aa	0.274 ± 0.052	2.88 ± 1.190	0.10 ± 0.04	0.072 ± 0.02	3.32 ± 1.07Aa	0.33 ± 0.08	0.90 ± 0.36	0.17 ± 0.03	0.08 ± 0.01	1.48 ± 0.32Ab
	Total	0.26 ± 0.01Bc	10.02 ± 0.08Aa	0.13 ± 0.04Bb	0.07 ± 0.01Bc	10.47 ± 0.02Aa	0.47 ± 518Bb	7.04 ± 1.190Ab	0.18 ± 0.04Bb	0.155 ± 0.02Bb	7.85 ± 1.07Ab	0.59 ± 0.08Ba	3.96 ± 0.36Ac	0.29 ± 0.03Ba	0.19 ± 14Ca	5.03 ± 0.32Ac
NFT	24	0.01 ± 0.00	0.18 ± 0.06	–	–	0.19 ± 0.06A	–	0.14 ± 0.051	–	–	0.14 ± 0.05A	0.01 ± 0.002	0.07 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.10 ± 0.00A
	25	0.01 ± 0.01	0.16 ± 0.12	72 ± 2	–	0.18 ± 0.124	0.03 ± 0.004	0.25 ± 0.002	0.01 ± 0.00	0.006 ± 0.002	0.30 ± 0.00A	0.02 ± 0.01	0.11 ± 0.04	0.01 ± 0.00	0.00 ± 0.00	0.14 ± 0.03B
	26	0.02 ± 0.01	0.40 ± 0.28	0.015 ± 0.00	0.02 ± 0.00	0.45 ± 0.28ABab	0.02 ± 0.006	0.65 ± 0.011	0.03 ± 0.00	0.028 ± 0.014	0.73 ± 0.03Aa	0.02 ± 0.01	0.32 ± 0.14	0.025 ± 0.00	0.01 ± 0.00	0.38 ± 0.12Ab
	27	0.10 ± 0.02	1.63 ± 0.37	0.01 ± 0.00	0.05 ± 0.01	1.77 ± 0.39Aa	0.05 ± 0.013	0.67 ± 0.121	0.04 ± 0.01	0.041 ± 0.019	0.80 ± 0.10Ab	0.04 ± 0.03	0.42 ± 0.08	0.020 ± 0.01	0.02 ± 0.00	0.50 ± 0.05ABc
	28	0.04 ± 0.01	1.44 ± 0.02	0.01 ± 0.01	–	1.48 ± 0.013a	0.07 ± 0.001	0.77 ± 0.045	0.02 ± 0.01	0.012 ± 0.023	0.87 ± 0.014b	0.02 ± 0.02	0.32 ± 0.01	0.005 ± 0.01	0.01 ± 0.01	0.36 ± 0.02Cc
	29	0.01 ± 0.00	1.13 ± 0.09	–	0.01 ± 0.01	1.14 ± 0.09a	0.09 ± 0.005	0.87 ± 0.165	0.01 ± 0.01	0.018 ± 0.025	0.99 ± 0.20a	0.04 ± 0.01	0.17 ± 0.01	0.031 ± 0.01	0.01 ± 0.01	0.25 ± 0.02Bb
	30	0.01 ± 0.00	1.10 ± 0.29	–	–	1.11 ± 0.30a	0.058 ± 0.001	0.513 ± 0.046	0.05 ± 0.01	0.023 ± 0.035	0.64 ± 0.23Ba	0.03 ± 0.02	0.12 ± 0.02	0.045 ± 0.00	0.03 ± 0.00	0.22 ± 0.03Cb
	31	0.26 ± 0.02	2.95 ± 0.04	0.085 ± 0.02	0.05 ± 0.01	3.35 ± 0.04Ba	0.277 ± 0.098	0.248 ± 0.003	0.20 ± 0.06	0.100 ± 0.056	0.82 ± 0.02Bb	0.15 ± 0.00	0.11 ± 0.02	0.112 ± 0.04	0.20 ± 0.06	0.58 ± 0.04Cc
	Total	0.44 ± 0.02Cb	8.99 ± 0.40Ba	0.121 ± 0.02Bc	0.13 ± 0.01Ab	9.67 ± 0.04Ba	0.603 ± 0.098Aa	4.109 ± 0.034Bb	0.36 ± 0.06Ca	0.227 ± 0.056Aa	5.30 ± 0.02Bb	0.35 ± 0.03Bc	1.65 ± 0.02Bc	0.253 ± 0.04Bb	0.29 ± 0.06Ba	2.54 ± 0.04Bc

Table 4. Average value of the weekly accumulated income per soilless culture system and salt treatment. Mean values ± standard deviation. Values with different letters differ significantly at the 95% level, according to Tukey's HSD test. Uppercase letters compare soilless culture systems for each salinity treatment. Lowercase letters compare salinity treatments for each soilless culture system

	DFT (€ m^{-2})			Perlite (€ m^{-2})			NFT (€ m^{-2})		
Week	S0	S1	S2	S0	S1	S2	S0	S1	S2
24	0 ± 0C	0 ± 0C	0 ± 0B	0.01 ± 0.00Bb	0.02 ± 0.00Ba	0 ± 0Bc	0.15 ± 0.05Aa	0.11 ± 0.04Aa	0.07 ± 0.00Ab
25	0.27 ± 0.09a	0 ± 0Cc	0.08 ± 0.02Bb	0.21 ± 0.07a	0.15 ± 0.03Bb	0.19 ± 0.04Ab	0.28 ± 0.09ab	0.33 ± 0.00Aa	0.18 ± 0.02Ab
26	0.30 ± 0.08Ba	0.12 ± 0.03Cb	0.14 ± 0.02Bb	0.54 ± 0.07A	0.45 ± 0.12B	0.51 ± 0.08A	0.60 ± 0.21Aab	0.85 ± 0.02Aa	0.45 ± 0.09Ab
27	0.76 ± 0.08Ca	0.42 ± 0.08Cb	0.40 ± 0.07Bb	1.29 ± 0.00Ba	1.01 ± 0.08Bb	0.98 ± 0.08Ab	1.93 ± 0.29Aa	1.44 ± 0.09Ab	0.82 ± 0.04Ac
28	2.15 ± 0.40Ba	1.02 ± 0.18Bb	1.29 ± 0.01Bb	2.54 ± 0.37Ba	2.00 ± 0.33Ab	1.62 ± 0.00Ac	3.05 ± 0.01Aa	2.08 ± 0.02Ab	1.08 ± 0.00Cc
29	3.65 ± 0.97a	1.73 ± 0.06Bb	1.73 ± 0.04Bb	3.98 ± 0.66a	2.94 ± 0.21Ab	2.12 ± 0.05Ac	3.95 ± 0.07a	2.86 ± 0.15Ab	1.27 ± 0.01Cc
30	4.75 ± 1.30a	3.35 ± 0.09b	2.70 ± 0.15Ac	4.95 ± 0.80a	3.44 ± 0.35b	2.66 ± 0.05Ac	4.84 ± 0.23a	3.35 ± 0.027b	1.43 ± 0.00Bc
31	7.10 ± 1.24ABa	4.94 ± 0.12Bb	3.24 ± 0.11Bc	8.16 ± 0.03Aa	6.05 ± 0.88Ab	3.78 ± 0.25Ac	7.48 ± 0.03Ba	3,93 ± 0.01Cb	1.81 ± 0.02Cc

Table 5. Cost-benefit analysis for each irrigation system, with the break-even point (BP indicated, as well as the distance to equilibrium for each case – mean values

		Yield (kg m^{-2})	Income (€ m^{-2})	*CF* (€ m^{-2})	CV (€ m^{-2})	CT (€ m^{-2})	Profit (€ m^{-2})	Profit / CT (–)	Selling price (€ kg^{-1})	BP (€ kg^{-1})	Distance to equilibrium (€ kg^{-1})	Precio equilibrio agua (€ m^{-3})
DFT	S0	9.66	7.10	4.56	1.04	5.53	1.58	0.29	0.74	0.58	0.16	2.52
	S1	7.01	4.94	4.51	0.76	5.21	−0.27	−0.05	0.70	0.75	−0.05	−0.05
	S2	4.88	3.24	4.35	0.53	4.83	−1.59	−0.33	0.66	1.00	−0.34	−5.61
Perlite	S0	10.48	8.16	3.75	1.14	4.98	3.19	0.64	0.78	0.47	0.31	4.12
	S1	7.85	6.05	3.58	0.87	4.50	1.55	0.35	0.77	0.57	0.20	3.75
	S2	5.03	3.78	3.47	0.56	4.05	−0.27	−0.07	0.75	0.80	−0.05	−0.50
NFT	S0	9.68	7.48	3.97	1.06	4.92	2.56	0.52	0.77	0.52	0.25	6.67
	S1	5.30	3.93	3.84	0.59	4.33	−0.40	−0.09	0.74	0.83	−0.09	−0.08
	S2	2.54	1.81	3.63	0.29	3.82	−2.02	−0.53	0.71	1.55	−0.83	−4.09

Between salt levels, the value hardly varies, except for DFT, due to the differences in the weighted average selling price. Thus, in the S0 treatment, the weighted average selling price for DFT was greater, and the equilibrium point lower, while for the S2 salt level, the mean weighted selling price was smaller and the equilibrium point higher (the relationship is inverse). Analogously, the value of production to obtain revenues is calculated.[31] (Fig. 4(B)). In control conditions (S0), the production was higher than the equilibrium point by 47%, 38%, and 25% for perlite, NFT, and DFT, respectively. For the salt treatment S1, production was 31% greater than the equilibrium point for perlite, 15% less than NFT, and 8% lower than DFT. For treatment S2, production was close to the equilibrium point only for perlite (8% below) while for DFT, and NFT, the production was far below the equilibrium point.

Table 5 shows the maximum price that water could have to reach equilibrium, supposing that the quality of water, and the rest of

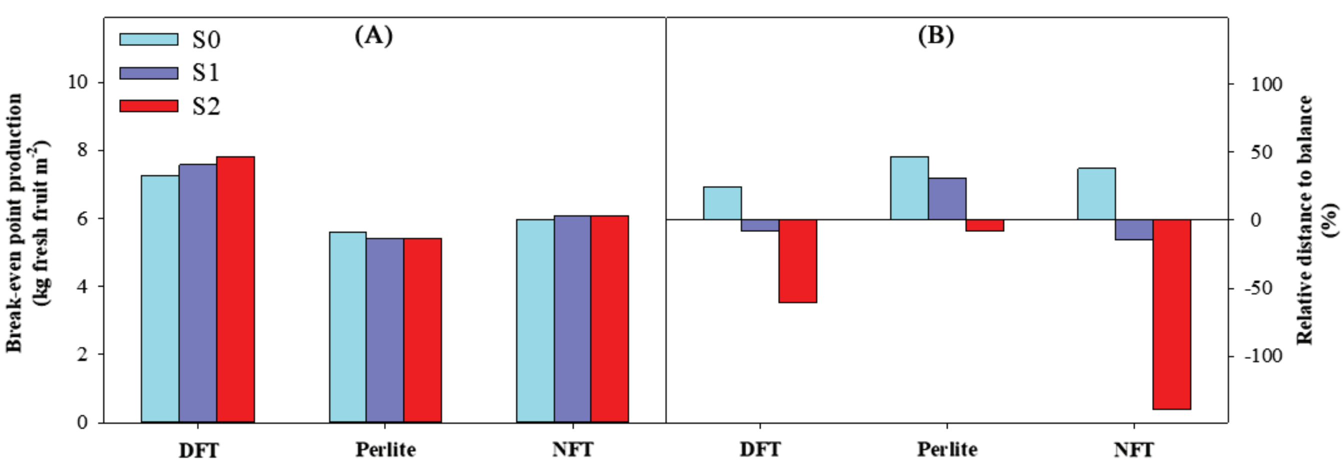

Figure 4. Break-even point production and relative distance to balance for the soilless culture systems at different salt treatments.

the factors that have an influence on profitability, are maintained constant. With S0 treatment, equilibrium is reached in the three soilless systems. However, when the salinity is increased, this is only reached for the S1 treatment with perlite. It is important to highlight that the NFT system allows for a greater increase in the price of water. When the profit is negative, the analysis does not make sense.

The improvement in the profitability of tomato production in greenhouses implies the reduction of costs and an increase in production. The results of this work indicate that, in the case of DFT, the low density of the crop resulted in limited production, and may have resulted in a greater size of the plants, which implied an increase in the costs of the phytosanitary treatments. The cost of maintenance labor was also very high, although this has a margin for improvement thanks to control applications and process automation. As for the salt treatment, cultivation with DFT was profitable with low-salinity irrigation water.

Cultivation with perlite was the most profitable of all the salt treatments. To improve profitability, it would be important to reduce the cost of the irrigation water and fertilization, i.e., the volume of substrate utilized could be reduced. Other research has demonstrated that these types of innovations are compatible with the economic profitability of the operation.[25]

In this case, one of the most important costs came from the consumption of energy. The NFT was the soilless system in which the plants were smaller and in which the economic equilibrium was maintained with a greater increase in the price of water. These results could indicate that perhaps the NFT could be better adapted to the growing of tomato plants with low-salinity irrigation water and a smaller size of the aerial part and shorter cycles. There is a growing interest in technologies that allow the movement of plants to the interior of the greenhouse, with the aim of increasing automation in the management of the crop to favor savings in labor costs. The use of the NFT system could therefore be suggested for use in urban installations, in vogue at the moment, due to the interest in bringing the centers of production closer to the centers of consumption. This is a type of closed system that also reduces the environmental impact.

An increase in the price of water could be motivated by many factors, scarcity being the most common. In this case, a reduction in the quality of water is probable, which would negatively impact final production. It is therefore necessary to consider all the factors that affect the economic profitability of tomato production in greenhouses in order to correctly perform the estimations.

CONCLUSIONS

The importance of the cultivation costs varied considerably depending on the soilless cultivation system. The increase in the salt concentration in the nutrient solution resulted in a generalized decrease in production, which was greater for plants grown with the NFT. The economic indicators supported the conclusion that the profitability of exploitation was reduced in the order perlite > NFT > DFT. Cultivation was profitable with the three soilless growing systems when using low-salinity water, and in perlite, water with intermediate salinity.

It is necessary to continue research on the management of irrigation and the economic results of the production of vegetables with the NFT, due to its potential beneficial effect on the consumption of water and fertilizers and contamination due to leaching. The NFT could be better adapted to the growing of tomato plants with a smaller size of the aerial part and shorter cycles. It would be useful to determine the economic viability of a greenhouse with fully automated crop management, including NFT and plant movement, or, in other production systems, such as urban installations.

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