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Assessment of Water Productivity and Economic Viability of Greenhouse-Grown Tomatoes under Soilless and Soil-Based Cultivations

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Abstract: Water scarcity has necessitated the adoption of water-saving techniques in both protected and non-protected farming. This study aimed to evaluate the performance of a water-saving soilless cultivation technique and compare it to conventional soil-based cultivation in protected farming. The soilless technique utilized local gravel and a mixture of peat moss, humin-substrate, and perlite in a 4:3:1.5 ratio. During the tomato growth cycle, three irrigation regimes were imposed using drip irrigation: 8 Lh^{-1} design discharge (D1) emitters, 6 Lh^{-1} design discharge (D0.75) emitters, and 4 Lh^{-1} design discharge (D0.5) emitters for both cultivation methods. Vegetative growth, fruit yield, and water consumption were measured and water productivity was determined. Additionally, an economic assessment was conducted by estimating and comparing economic coefficients for both cultivation methods. Estimated coefficients included revenues, net profit, benefit–cost ratio, breakeven levels of production and prices, revenues over variable cost, and revenues on investment. The tomato fruit yield under soil-based cultivation surpassed the yield under soilless cultivation. Water productivity under soilless cultivation was nearly double (24.3 kg m^{-3}) that of soil-based cultivation (15.5 kg m^{-3}). Soilless cultivation saved 50% of the irrigation water applied by the conventional soil-based method, conserving energy and protecting the soil from deterioration. Revenues and net profits, driven by higher yield and lower variable costs, favored soil-based cultivation. The economic assessment demonstrated that both cultivation methods were economically viable. However, the soil-based cultivation method was more profitable due to its higher fruit yield. Overall, the results of this study suggest that the soilless cultivation technique is a feasible option for water-saving cultivation. However, the soil-based cultivation method remains more profitable due to its superior fruit yield. The soilless cultivation technique offers significant water savings but needs further improvements to achieve comparable economic returns to traditional farming.

Keywords: low-tech greenhouse; tomato; soilless cultivation; soil-based cultivation; water productivity

Citation: Al-Khateeb, S.A.; Zeineldin, F.I.; Elmulthum, N.A.; Al-Barrak, K.M.; Sattar, M.N.; Mohammad, T.A.; Mohmand, A.S. Assessment of Water Productivity and Economic Viability of Greenhouse-Grown Tomatoes under Soilless and Soil-Based Cultivations. *Water* **2024**, *16*, 987. https://doi.org/10.3390/w16070987

Academic Editors: Xinchun Cao, Jing Liu and Qingling Geng

Received: 31 October 2023
Revised: 7 December 2023
Accepted: 11 December 2023
Published: 28 March 2024

1. Introduction

Water is a scarce resource in arid and semi-arid regions, particularly in the Kingdom of Saudi Arabia (KSA). In these regions, farmers are increasingly adopting protected farming techniques, such as plastic mulch, tunnel farming, greenhouses, and hydroponic systems to meet the year-round demands of fresh agricultural food commodities [1]. Soil is crucial for plant growth, providing nutrients, water, and air. However, some soil types, such as coarse-textured sandy soils that are prevalent in greenhouse soil profiles, pose limitations to plant growth. Sandy soils are characterized by high permeability, low water-holding capacity, and the presence of pathogenic organisms and nematodes [2]. To overcome the challenges posed by sandy soils in greenhouses, soilless cultivation techniques provide an alternative strategy to enhance water use efficiency [3–5]. A study by Estidamah [6] demonstrated that when a soilless cultivation method with a drain collection system is implemented, water consumption for greenhouse tomatoes could be reduced by 33% (1014 Lm^{-2}) compared to soil-based cultivation (1518 Lm^{-2}). The daily water requirement of a tomato plant varies depending on the growing system [7]. A soilless cultivation system using a combination of cocopeat, perlite, and vermiculite (50:25:25) requires less water than a system using two substrates (50:50) or one substrate. The soilless cultivation system produced more tomatoes per unit of water, with a water productivity of 83.4 kg m^{-3} [8].

Tomato (*Solanum lycopersicum* Mill.) is one of the widely cultivated and highly consumed vegetable crops globally, particularly in semi-arid regions [9]. Tomato cultivation in the Mediterranean region necessitates a high water supply and significant fertilization demands. Studies have shown that hydroponically-grown tomatoes exhibit nutritional benefits compared to conventionally soil-grown counterparts [10]. Greenhouse tomato cultivation in Saudi Arabia accounts for nearly 50% of the country's total tomato production [11]. Sandy soils dominate the majority of cultivated areas in Saudi Arabia, rendering them susceptible to water scarcity [12]. Therefore, employing alternative water-saving techniques is imperative to improve water use efficiency in tomato production in the Kingdom [13].

A study conducted in southeastern Spain compared the economic viability of three different tomato-growing methods [14]. The open-field method, utilizing perlite as a substrate, emerged as the most expensive approach due to the substantial irrigation and fertilization costs. The hydroponic deep flow method was ranked as the second most expensive option due to the high costs associated with phytosanitary treatments and maintenance. The nutrient film technique (NFT) method proved to be the least expensive option, owing to its low energy consumption. Similarly, a study undertaken at the Saidapur farm of the University of Agricultural Sciences in Dharwad aimed to identify the optimal levels of irrigation and soilless media for growing tomatoes for the fresh market under hi-tech greenhouse conditions [8]. The study revealed that the highest fruit yield and weight were achieved when tomatoes were grown under drip irrigation at 100% Epan and a soilless mixture of cocopeat, perlite, and vermiculite in a 50:25:25 ratio. This combination also yielded higher gross and net returns compared to the other treatment combinations. Despite the various advantages characterizing the soilless cultivation technique, especially in regard to water conservation, it has some limitations related to its application on a commercial scale, which requires technical knowledge and high initial investment. The considerable cost expenditure limits the application of soilless culture to high-value crops [2].

This study delved into the effects of two different tomato-growing methods: hydroponic soilless (HS_{less}) as an open system technique, and a conventional soil-based (CS_{based}) cultivation. It sought to investigate how these two methods influenced vegetative plant growth, fruit yield, water use efficiency, and the economic viability of greenhouse-grown tomato production. Moreover, the study intended to introduce a water-saving, inexpensive, and environmentally sound method, utilizing local gravel and a mixture of peat moss, humin-substrate, and perlite in ratios of 4:3:1.5 for greenhouse tomato production.

2. Materials and Methods

The study experiment was conducted in a greenhouse at the research and training station of King Faisal University, Saudi Arabia (25°17.1347′ N and 49°29.1889′ E). In this study, the following two factors were considered:

1. Cultivation methods:

A: CS_{based} cultivation.
B: HS_{less} cultivation.

2. Irrigation Regimes with Emitters' Design Discharge (D):

A: Emitter of Design discharge of 4 Lh^{-1} (D1).
B: Emitter of Design discharge of 6 Lh^{-1} (D0.75).
C: Emitter of Design discharge of 8 Lh^{-1} (D0.5).

2.1. Experimental Design

A two-factorial experiment was set up as split-plot design with three replications in the greenhouse (Figure 1). The first factor consisted of two cultivation methods (CS_{based} and HS_{less}), while the second factor included three levels of irrigation regimes imposed with emitters of 4, 6, and 8 Lh^{-1} design discharge.

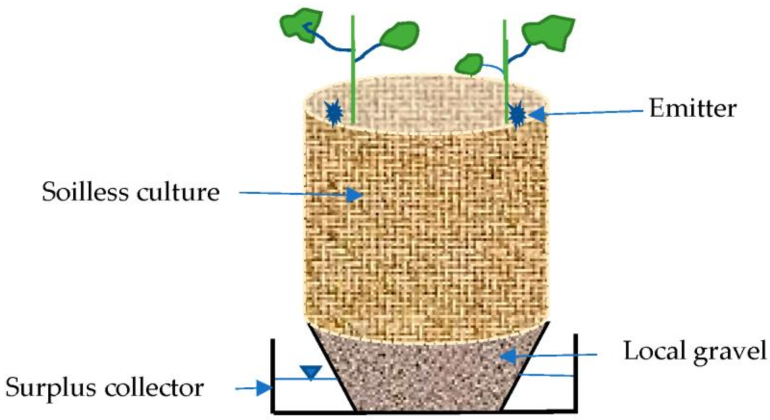

Figure 1. Sketch of a pot containing soilless culture, supporting two plants.

2.2. Cultivation Methods

The CS_{based} is a conventional soil-culture practice that is prevalent in most of the low-tech greenhouses of the KSA for growing vegetables. Initially, soil samples were taken from the CS_{based} plot to determine its soil profile physical properties, as shown in Table 1.

Table 1. Physical properties of soil profile of soil-based plot.

Soil Depth (cm)	θ_{FC}	θ_{PWP} (cm^3/cm^3)	AWC	OM (%)	Soil Particle Distribution (%)			
					2–0.5 mm	0.5–0.25 mm	0.25–0.05 mm	< 0.05 mm
0–15	0.155	0.09	0.07	3	31.3	49.5	17.2	2.0
15–30	0.143	0.084	0.06	2	29.0	51.2	18.3	1.5
30–60	0.123	0.062	0.06	1	28.0	51.9	19.1	1.0

Notes: θ_{FC}—field capacity; θ_{PWP}—permanent welting point; **AWC**—available water content; **OM**—organic matter.

In this study, the HS_{less} was an open system where water and nutrients were supplied as in the conventional soil culture, but the surplus of the water and nutrients (about 15%) was manually collected and reused. The soilless culture of the HS_{less} was made up of peat moss, humin-substrate, and perlite in the ratio of (4:3:1.5). Peat moss is capable of absorbing 16 to 36 times its dry weight, has a low pH range from 3.4 to 4.8 and a high porosity of more than 95%. The humin-substrate contained many humic acids and was characterized by high water absorption capacity. Perlite is a natural inorganic mineral used as a hydroponic medium; it stimulates root growth and helps drain excess water. The HS_{less} cultivation plot consisted of 32 pots (20 L) perforated from the bottom and placed in receptacles for surplus collection. Local gravel was loaded up to 10 cm into each pot, then an equal amount of soilless culture was placed on the gravel, as shown by the plot sketch (Figure 1).

2.3. Assessment of Drip Irrigation Emitters

In each of the two cultivation method plots, as depicted in Figure 2, two parallel lateral driplines were positioned on the soil ridges for the CS_{based} method and on the pots for the HS_{less} method. The two driplines were spaced 30 cm apart, and each dripline was equipped with emitters spaced 40 cm apart. In both cultivation plots, the first eight pairs of emitters on each lateral dripline had a design discharge of 4 Lh^{-1} (subplot-I), the middle eight pairs had a design discharge of 6 Lh^{-1} (subplot-II), and the last eight pairs had a design discharge of 8 Lh^{-1} (subplot-III). An operating pressure of 150 kPa was maintained throughout the experiment during irrigation of the two cultivation plots. Before transplanting, the discharges of the emitters under 150 kPa were measured. The actual emitter discharges were 3.67, 5.55, and 7.30 Lh^{-1}, respectively, for design emitter discharges of 4, 6, and 8 Lh^{-1}.

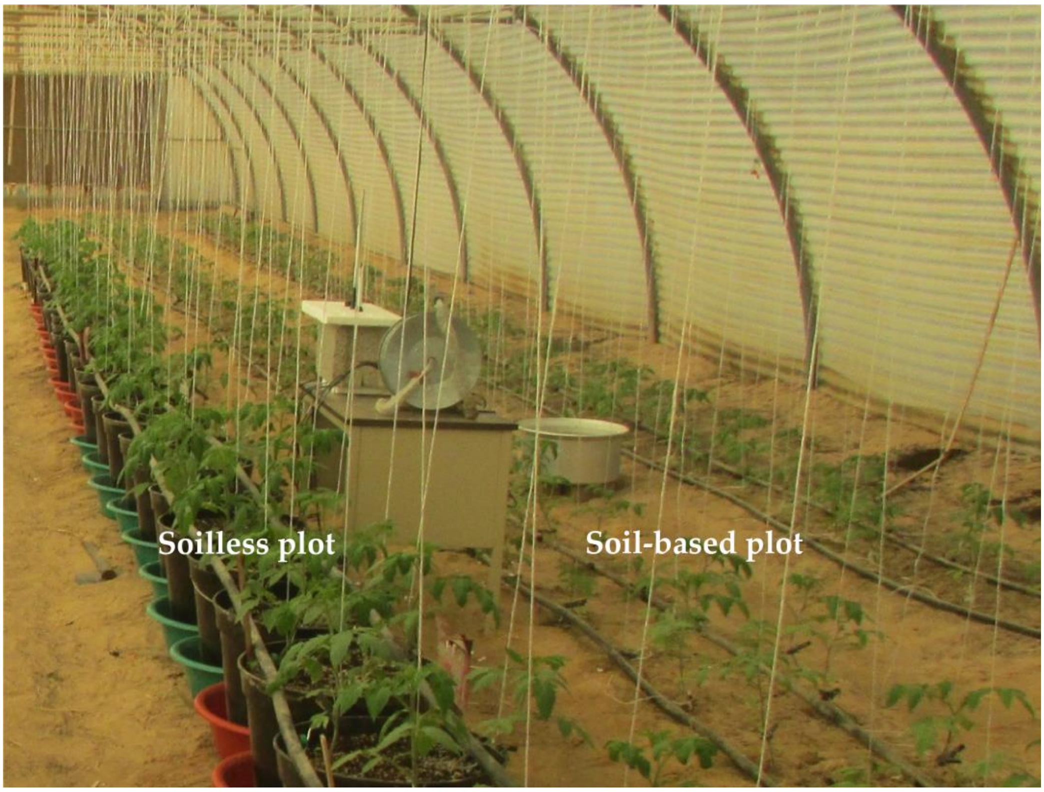

Figure 2. Experimental soil-based and soilless cultivation plots.

2.4. Water Requirement and Irrigation Scheduling

In the control section of the drip irrigation system, a reservoir filled with groundwater (1.3 dS m^{-1}) was connected to a water pump, timer, solenoid valves, and digital flow water meters. This control section supplied and measured irrigation water delivered to the HS_{less} and CS_{based} cultivation plots. Water requirement per day for tomato plants grown in the CS_{based} system was determined using the following formula:

$$V = \frac{1}{1000} \times E_{pan} \times SA \quad (1)$$

where:

V: Volume of water irrigation (m^3), E_{pan}: Evaporation rate from a class A evaporation pan located in the greenhouse (mm), SA: Shadow Area (m^2)

The irrigation duration for the CS_{based} plot was determined using the following relation:

$$\text{Irrigation duration} = \frac{\text{Volume of water to be applied (L)}}{\text{Average discharge of the emitters (L/h)}} \quad (2)$$

The irrigation duration for the HS_{less} cultivation plot was determined during the growing season when 15% of the surplus water was observed in receptacles.

2.5. Water Productivity

Water productivity (WP) under the HS_{less} and CS_{based} cultivations was determined by the ratio between the total economic yield of the greenhouse tomatoes (kg) and the amount of water applied (m^3) to a specific treatment during the growing season. It was computed using the following formula.

$$WP = \frac{\text{Economic yield}}{\text{Total applied irrigation water}} \quad (3)$$

2.6. Benefit–Cost Analysis

Benefit–cost analysis is a tool used to assess the economic viability of an investment. It involves comparing the costs of an investment to its benefits to determine whether the investment is worthwhile [11]. The benefit–cost ratio (BCR) is a common measure used in benefit–cost analysis. The BCR is calculated by dividing the total benefits of an investment by the total costs. A BCR greater than one indicates that the investment is beneficial, while a BCR less than one indicates that the investment is not beneficial. The BCRs for the two cultivation systems were compared for the greenhouse tomato crop using the following formula:

$$BCR = \frac{B}{C} \quad (4)$$

where BCR, B, and C denote the benefit–cost ratio, benefits, and costs, respectively.

2.7. Breakeven Levels of Production and Prices

Breakeven analysis is a financial tool that is used to determine the number of units of a product that need to be sold to cover the cost of production. The breakeven point is the point at which the total revenue from sales equals the total cost of production. At the breakeven point, the business is not making a profit, but it is also not losing money [15,16]. The breakeven production level (BP) can be calculated using the following equation:

$$BP = \frac{FC}{P - VC} \quad (5)$$

where:

BP is the breakeven production level,
FC is the fixed cost,
P is the price per unit of product,
VC is the variable cost per unit of product.

The gap between the price and the variable cost per unit measures the contribution of each item produced to cover the investment's fixed costs (FC). Production at the breakeven point indicates that the investment revenue covers the cost of production (the profit at the breakeven point is zero; revenue is equal to cost). Production, above or below breakeven levels, indicates that the enterprise is operating at a profit or loss, respectively [17]. The breakeven prices, which represent prices that cover costs at specific sales volumes, were estimated.

2.8. Revenues over Variable Cost and Revenues on Investment

The hydroponic greenhouse production budget from Ohio State University [18] was used as a starting point to estimate the revenues over variable costs and revenues on investment for the two cultivation methods. The budget was modified to reflect the specific costs and revenue streams of each method.

Revenues and costs were calculated using current Saudi Riyal (SAR) prices. The total cost includes variable and FC. Fixed costs are the costs of setting up the investment, and they will be incurred even if no production is taking place. Variable costs are the costs of production inputs, and they are incurred when the production process begins. Total and net revenues were estimated for each production system by subtracting variable and total costs from total revenues.

The straight-line method [19] was used to estimate FC during the production period. This method calculates depreciation by dividing the asset's cost by its useful life. The following equation was used:

$$FC = \frac{IC - RV}{UL} \quad (6)$$

where:

FC is the fixed cost,
IC is the initial cost,
RV is the residual value,
UL is the useful life.

The fixed and variable costs of the HS_{less} and CS_{based} methods are shown in Appendix A Tables A1–A3. Explicit costs are those that require a direct outlay of money, such as wages, rent, and materials. Implicit costs are those that do not involve an immediate outlay of money, but represent the opportunity cost of using resources that could be used for other purposes.

3. Results and Discussion

3.1. Measured Actual Irrigation Amounts

Initially, during the first month of the tomato growth cycle, the results showed that the actual applied irrigation water was 0.58, 0.87, and 1.15 L per plant per day for the HS_{less} cultivation plot, and was 1.31, 1.95, and 2.58 L per plant per day for the CS_{based} cultivation plot, for D0.5, D0.75, and D1, respectively. Considering the irrigation regime of the high discharge emitters (D1), the HS_{less} cultivation method used 50% less irrigation water than the CS_{based} cultivation method. This result agreed with the outcome obtained by Estidamah (6). The amount of irrigation water used by both methods increased with the growth of the tomato plants (Figure 3). The difference in irrigation amounts between the two approaches could be attributed to the difference in the water-holding capacity of the soil and the hydroponic substrate mixture. Surplus drainage from the HS_{less} was reused (15%), while surplus drainage from the CS_{based} cultivation method beyond the root zone was lost through deep percolation.

3.2. Vegetative Growth Response

Table 2 shows the least significant difference (LSD) determined from all-pairwise comparison tests of plant height and number of leaves for the cultivation methods, emitters' design discharge (D), and growing time of the tomato plants. During the late growing time, significant pairwise differences were observed among the plant height means for different emitter discharges (D0.5, D0.75, D1) and under both cultivation methods (CS_{based} and HS_{less}). However, during the early growing time, no significant pairwise differences were observed. Regarding the mean number of leaves, significant pairwise differences between the two cultivation methods were only observed for emitter discharges of D0.75 during the late growing time.

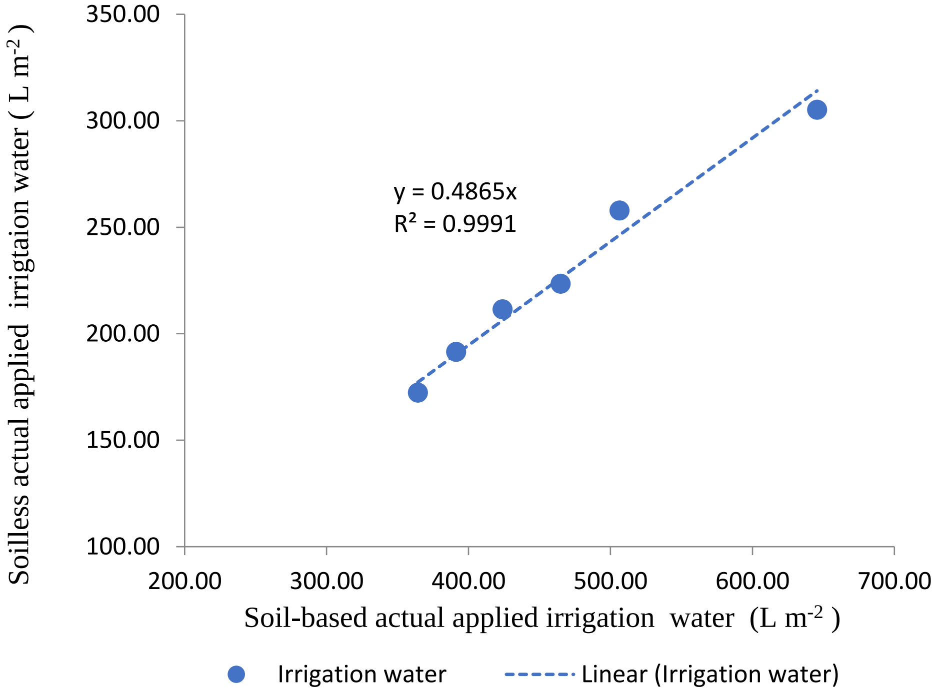

Figure 3. Tomato growing season cumulative irrigation water.

Table 2. Mean of heights and leave numbers during the early and late growth stages.

Cultivation Method	Emitters' Discharge (Lh^{-1})	Growing Time	Height (cm)	Homogeneous Groups	Number of Leaves	Homogeneous Groups
CS_{based}	D1	16-December	27.63	V	6.3	WY
HS_{less}	D1	16-December	23.37	V	5.7	Y
CS_{based}	D0.75	16-December	26.17	V	6.3	WY
HS_{less}	D0.75	16-December	24.53	V	5.7	Y
CS_{based}	D0.5	16-December	28.85	UV	6.6	VY
HS_{less}	D0.5	16-December	23.78	V	6.1	XY
CS_{based}	D1	7-March	254.88	A	28.3	A
HS_{less}	D1	7-March	205.44	C	25.9	AD
CS_{based}	D0.75	7-March	242	B	26.9	AC
HS_{less}	D0.75	7-March	199.56	CD	23.8	DG
CS_{based}	D0.5	7-March	253.38	A	27.3	AB
HS_{less}	D0.5	7-March	196.69	CD	25.2	BE

The study's findings indicate a strong linear relationship between the average plant height growths in the two cultivation methods (Figure 4). The coefficient of determination (R2) of 0.98 suggests that the plant height growth for the two cultivation methods was nearly identical. This implies that approximately 50% of irrigation water could be saved by employing the HS_{less} cultivation method instead of the CS_{based} cultivation method in greenhouses with homogenous sandy soil profiles.

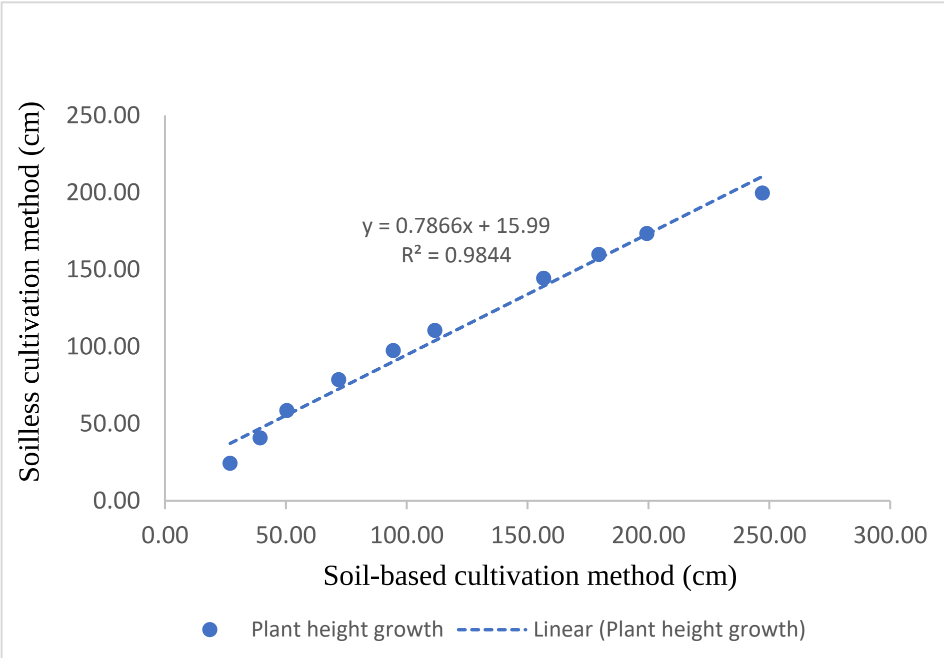

Figure 4. Plant height growth under soilless and soil-based cultivations.

The analysis of variance (ANOVA) for tomato plant heights, presented in Table 3, revealed significant differences among the cultivation methods, emitters' discharge, and growing time (p = 0.05). These findings were corroborated by the LSD all-pairwise comparison tests in Table 2. Additionally, significant interactions were observed between the cultivation methods and the emitters' discharge (D), as well as between the cultivation methods and growing time (T). However, the interaction between the cultivation methods, emitters' discharge (D), and the growing time (T) exhibited no differences (p = 0.998).

Table 3. Analysis of variance for tomato plant height.

Source	DF	SS	MS	F	P
Rep	3	1976	659		
$CS_{based}HS_{less}$	1	7317	7317	128.22	0
Emitter discharge (D)	2	1111	555	9.73	0.0001
Time (T)	9	980,034	108,893	1908.18	0
$CS_{based}HS_{less}$*D	2	806	403	7.07	0.0011
$CS_{based}HS_{less}$*T	9	16,720	1858	32.56	0
D*T	18	445	25	0.43	0.979
$CS_{based}HS_{less}$*D*T	18	291	16	0.28	0.998
Error	177	10,101	57		
Total	239	1,018,801			
Grand Mean		113.95	CV	6.63	

Note: the * refers to the interaction between two source factors.

3.3. Tomato Fruit Yield and Components' Responses

The average tomato fruit yield (TFY) per square meter was determined, along with the number of fruits and fruit diameters (Tables 4 and 5). During the early picking times, the TFY of the HS_{less} cultivation was higher than the CS_{based} cultivation, while the opposite was true for the late picking (Table 5, Figure 5). Using the emitters' discharge of D0.75 compared to the D1, reduced the average TFY per square meter under the HS_{less} by 7.9%, and under the CS_{based} by 11.8%. On the other hand, using the D0.5 emitters' discharge reduced it by 38.9% under the CS_{based} and 25.1% under the HS_{less}. Therefore, the reductions were more pronounced at the use of D0.5 emitters' discharge under both cultivation systems than at the use of the D0.75. In comparison between the cultivations, the TFY under the HS_{less} was 7.4% less than the CS_{based} at D1 and 11.3% at D0.75, but increased by 13.1% with D0.5 emitters' discharge.

Table 4. Emitters' discharge impacts on tomato fruit yield under the cultivation methods.

Picking Date	CS_{based} Cultivation kg/Plant (STDEV)			HS_{less} Cultivation kg/Plant (STDEV)		
	D1	D0.75	D0.5	D1	D0.75	D0.5
21 March	0.10 (±0.05)	0.10 (±0.06)	0.11 (±0.04)	0.42 (±0.13)	0.41 (±0.2)	0.31 (±0.05)
30 March	0.32 (±0.06)	0.24 (±0.1)	0.21 (0.12)	0.28 (±0.06)	0.25 (±0.2)	0.27 (±0.04)
7 April	0.35 (±0.05)	0.28 (±0.03)	0.24 (±0.06)	0.71 (±0.25)	0.40(±0.16)	0.32 (±0.08)
17 April	0.69 (±0.09)	0.80 (±0.09)	0.31 (±0.057)	0.20 (±0.06)	0.33 (±0.16)	0.27 (±0.07)
26 April	0.29 (±0.11)	0.26 (±0.12)	0.24 (±0.04)	0.14 (±0.03)	0.12 (±0.02)	0.10 (±0.04)
18 May	0.26 (±0.05)	0.17 (±0.11)	0.13 (±0.06)	0.12 (±0.04)	0.15 (±0.08)	0.13 (±0.05)
TFY	2.02	1.86	1.23	1.87	1.65	1.40
TFY m^{-2}	16.16	14.88	9.84	14.96	13.2	13.2

Table 5. Impacts of HS_{less} and soil-based cultivations on average tomato fruit yield and components for irrigation by emitters' discharge of D1.

Picking Date	CS_{based} Cultivation		HS_{less} Cultivation	
	Number of Fruits per m^2(STDEV)	Fruit Diameter (cm) per m^2 (STDEV)	Number of Fruits per m^2 (STDEV)	Fruit Diameter (cm) per m^2 (STDEV)
21 March	1 (±0.22)	7.2 (±0.86)	3 (±0.99)	5.50 (±0.22)
30 March	2 (±0.42)	6.9 (±0.43)	3 (±0.90)	6.7 (±0.48)
7 April	4 (±0.67)	5.7 (±0.37)	7 (±1.79)	6.2 (±0.33)
17 April	7 (±1.47)	4.5 (±0.37)	8 (±1.64)	5.3 (±0.41)
26 April	6 (±1.11)	4.5 (±0.36)	4 (±0.62)	5.3 (±0.35)
18 May	8 (±2.24)	3.7 (±0.89)	7 (±0.96)	3.9 (±0.46)
	Total = 28	Average dia. = 5.4	Total = 32	Average dia. = 5.5

(**A**) (**B**)

Figure 5. (**A**) Early season tomato fruit response, (**B**) Late season tomato fruit response.

The outcomes showed that the number of tomato fruits and weights were increasing under the CS_{based} cultivation during the first four fruit picks but were inconsistent under the HS_{less} cultivation. As shown in Table 5, the total number of fruits and weights during the first picks were higher with the HS_{less} than with the CS_{based}. Moreover, the total TFY produced by the HS_{less} per square meter for D1 design discharge (8 Lh^{-1}), as shown in Table 4, was 92.5% of the CS_{based} production.

The number per square meter and weight of tomato fruits per plant decreased at the end of the growing season for all irrigation regime treatments (D0.5, D0.75, and D1) as shown by Tables 4 and 5. This was likely due to the hot weather conditions outside the greenhouse in April and May. The average diameter of the tomato fruits per square meter, as shown in Table 5, also decreased under both cultivation methods. Under the D1 design discharge (8 Lh^{-1}), as shown in Table 4, the average TFY of the greenhouse tomatoes was 2.02 kg m^{-2} (20.2 tons ha^{-1}) for the CS_{based} cultivation method and 1.87 kg m^{-2} (18.7 tons ha^{-1}) for the HS_{less} cultivation method. During the growth cycle, the amount of irrigation water received per square meter was 0.1306 m^3 for the CS_{based} cultivation method and 0.07688 m^3 under the HS_{less} cultivation method. This means, under D1 design discharge, the water use efficiency of the CS_{based} cultivation method was 15.5 kg m^{-3}, while the water use efficiency of the HS_{less} cultivation method was 24.3 kg m^{-3}. Therefore, the HS_{less} cultivation method (mixed substrates media) increased water use efficiency by 56.8% compared to soil-based cultivation. These results agreed with the research outcome of [20]. Furthermore, it took 64.5 L of water to produce 1 kg of tomatoes using the CS_{based} method, while it took 41.2 L of water using the HS_{less} method.

One-way ANOVA analysis was performed to test the difference in tomato fruit yield under the adopted three irrigation regimes (100% Epan, 80% Epan, and 70% Epan) under soilless and soil-based cultivations (HS_{less} and CS_{based}). Based on the results, the calculated F statistic was equal to 0.78 (sig. 0.467), and 0.37 (0.695) for the soil-based and soilless cultivations methods, respectively, indicating statistically insignificant differences in tomato fruit yield between the adopted irrigation regimes. Hence, the null hypothesis of no significant difference between groups is accepted. A two-tailed t test was conducted to compare the means of tomato fruit yields under the two cultivation methods. The results obtained accepted the null hypothesis of equal means; the t statistic equals 0.167 (sig. 0.868) indicating insignificant differences in tomato fruit yield between the two cultivation methods.

The ANOVA for TFY showed that there were significant differences in TFY when different emitters were used for irrigation, but there were no significant differences in TFY when different cultivation methods were used (p = 0.05) (Table 6). Additionally, there were significant differences in TFY when fruit was picked at different times, and there were also significant interactions between fruit picking time (PT) and cultivation method. However, there were significant differences in the TFY for the interaction of the cultivation methods, emitters' discharge, and picking times. In other words, the type of emitter used for irrigation had a significant impact on TFY, but the type of cultivation method did not. The time at which fruit was picked also had a significant impact on TFY, and the impact of the fruit picking time was different for different cultivation methods. These results suggest that the type of emitter used for irrigation and the time at which fruit is picked are both important factors that can affect TFY.

Table 6. Analysis of variance for tomato fruit yield (Statistix 8.1).

Source	DF	SS	MS	F	P
Rep	3	153,855	51,285		
$CS_{based}HS_{less}$	1	2525	2525	0.3	0.5874
D	2	113,101	56,550	6.64	0.0019
Picking Time (PT)	5	460,463	92,093	10.81	0
$CS_{based}HS_{less}$*D	2	14,949	7475	0.88	0.419
$CS_{based}HS_{less}$*PT	5	649,497	129,899	15.24	0
D*PT	10	59,609	5961	0.7	0.723
$CS_{based}HS_{less}$*D*PT	10	52,505	5250	0.62	0.7972
Error	105	894,865	8523		
Total	143	2,401,369			
Grand mean		246.37	CV	37.47	

Note: PT = Picking Time. The * refers to the interaction between two source factors.

3.4. Economics of Tomato Fruit Production

The fixed cost per square meter was estimated at 4.4 SAR for both cultivation methods. This similarity in fixed costs stems from the comparable nature of the two systems (Table 7). However, the HS_{less} system incurred slightly higher variable costs than the CS_{based} cultivation system due to the additional expenses associated with hydroponic irrigation. This result is supported by the results obtained by [2,14]. The CS_{based} system produces a higher yield of tomatoes, translating into increased revenues and profits. Variable costs represent the most significant component of total costs for both systems. Variable costs surpassed fixed costs for both methods, a result attributable to the extended useful life of fixed cost items, leading to reduced depreciation of fixed cost assets. Variable costs for tomato cultivation under the HS_{less} and CS_{based} systems constitute 80% and 78% of total costs, respectively. Table 8 illustrates the findings associated with the benefit–cost analysis for selecting the optimal economic investment. The benefit–cost analysis for selecting the economic investment corroborates the aforementioned results (Table 8). The benefit–cost analysis demonstrates the economic viability of both systems, with benefit–cost ratios of 2.6 and 2.2 for CS_{based} cultivation and HS_{less} cultivation, respectively. While, the CS_{based} cultivation system exhibits slightly higher profitability, both systems represent viable options for tomato cultivation.

Table 7. Yield, costs, price, and revenues (in SAR) for tomato HS_{less} and CSb_{ased} cultivations for irrigation with emitters' discharge of D1.

Method	Hydroponic Soilless	Conventional Soil-Based
yield kg/m^2	7.48	8.08
fixed/m^2	4.4	4.4
variable/m^2	17.6	15.8
price/kg	6.5	6.5
revenue/m^2	48.6	52.52
VC + FC	22	20.2
net profit/m^2	26.62	32.32
fixed cost/kg	0.58	0.54
variable cost/kg	2.35	1.96
price/kg	6.5	6.5
profit/kg	3.56	4

Note: Source: Authors' computations based on Appendix A.

Table 8. Benefit–cost ratio of tomato production for HS_{less} and CS_{based} methods for irrigation with emitters' discharge of D1.

Cultivation Method	Revenue/m^2	VC + FC	Benefit/Cost
Hydroponic soilless	48.6	22	2.2
Conventional soil-based	52.52	20.2	2.6

Note: Source: Authors' computations based on Appendix A.

Both conventional and hydroponic farming systems are economically viable, generating positive revenues that exceed both variable and total costs (Table 9). However, the CS_{based} system appears to be more profitable than the HS_{less} system.

Table 9. Revenues on investment and over variable cost for tomato production under HS_{less} and CS_{based} cultivation methods for emitters' discharge of D1.

Method	Hydroponic Soilless	Conventional Soil-Based
Variable cost/m^2	17.6	15.8
Fixed cost/m^2	4.4	4.4
Total cost/m^2	22	20.2
Revenue/m^2	48.6	52.52
Revenue over variable cost/m^2	31	36.72
Revenue on investment/m^2	26.6	32.32

Note: Source: Authors' computations based on Appendix A.

Referring to Tables 8 and 9, both systems are economically viable options for tomato production. Benefits and revenue more than doubled the total cost for both systems. However, the conventional CS_{based} system is slightly more profitable in comparison to the HS_{less} system. The concerns related to water scarcity in Saudi Arabia, where the majority of cultivated areas are dominated by sandy soils (8) and 50% of tomato production is under greenhouse cultivation systems (7), necessitates the use of alternative water-saving techniques (9). The objective of developing suitable water-saving systems is to improve the water use efficiency of tomato cultivation. Hence, although profitability is higher for the CS_{based} system, water-saving concerns give the HS_{less} system the advantage over the CS_{based} system.

The breakeven prices for tomato cultivation under the two systems are shown in Table 10 (profit at the breakeven price equals zero). The HS_{less} method had higher breakeven prices to cover variable and total costs per kg, due to higher variable and total costs associated with a lower yield of tomatoes cultivated under the hydroponic greenhouse system, contradicting the results obtained by [8]. Subtracting total cost per kg from market price, the profit per kilogram of tomatoes was 3.56 for the HS_{less} method and 4 for the CS_{based} method. Based on the estimated breakeven volume of production for the period considered, the breakeven yield for the hydroponic soilless system was calculated at around 1.05 kg m^{-2}, which is 6.43 kg m^{-2} below the actual yield of 7.48 kg m^{-2}. In contrast, the breakeven yield per square meter for the CS_{based} method was estimated at 0.96, around 7.12 kg m^{-2} below the actual yield of 8.08 kg m^{-2} (Tables 1 and 4). Since fixed cost and prices are the same for both systems, the difference in breakeven yield for the two systems arises from the difference in contribution margin, which is influenced by per unit variable cost.

Table 10. Breakeven prices and levels of tomato production under HS_{less} and CS_{based} cultivation methods for irrigation with emitters' discharge of D1.

Cultivation Method	Breakeven Price/Yield/Production	Value
HS_{less}	Breakeven price to cover the variable cost	2.35
	Breakeven price to cover the total cost	2.93
HS_{less}	Breakeven price to cover the variable cost	1.96
	Breakeven price to cover the total cost	2.5
HS_{less}	Breakeven volume for the period (163 days)	30.4 Kg
	Breakeven yield Kg/m^2 (area 32 m^2)	0.95
	Actual yield Kg/m^2	7.48
HS_{less}	Breakeven volume for the period (163 days)	53.8 Kg
	Breakeven yield Kg/m^2 (area 32 m^2)	1.7
	Actual yield Kg/m^2	8.08

Note: Source: Authors' computations based on Appendix A.

4. Conclusions

This study demonstrated that the HS_{less} cultivation method is a more water-efficient and environmentally friendly approach to greenhouse vegetable production compared to the CS_{based} method. It offers the potential to conserve irrigation water and improve water productivity. Notably, the water productivity of HS_{less} cultivation was nearly 50% higher than that of CS_{based} cultivation, indicating that the same amount of water produced a greater yield of tomatoes. Additionally, the HS_{less} cultivation method eliminates the need for soil sterilization, which can release harmful chemicals into the environment. While both cultivation methods were profitable, the CS_{based} system yielded higher revenue and profitability. These findings highlight the trade-off between the CS_{based} method's higher economic returns and the HS_{less} method's water conservation advantages. As climate change and population growth strain water resources, the demand for water-efficient agricultural practices will likely increase. Under these circumstances, the HS_{less} cultivation method offers promising future prospects for water-efficient and environmentally friendly greenhouse vegetable production, though further research is needed to assess its economic feasibility for a wider range of crops. Further research on water productivity and economic returns for other crops is recommended by the authors. Moreover, future research on product quality, in terms of nutritious value, for the two systems is suggested.

Author Contributions: Conceptualization, S.A.A.-K., K.M.A.-B. and T.A.M.; Methodology, F.I.Z., N.A.E. and T.A.M.; Validation, M.N.S.; Formal analysis, F.I.Z. and N.A.E.; Investigation, K.M.A.-B.; Data curation, M.N.S.; Writing—original draft, F.I.Z., N.A.E., T.A.M. and A.S.M.; Writing—review & editing, S.A.A.-K., N.A.E., M.N.S. and A.S.M.; Visualization, S.A.A.-K.; Supervision, K.M.A.-B.; Funding acquisition, S.A.A.-K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by King Abdulaziz City for Science and Technology grant number 10-WAT1150-06.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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

Appendix A

Table A1. Fixed and variable costs for tomato under hydroponic soilless and conventional soil-based cultivation methods.

Total Area of the Greenhouse 346.5 m^2						
Item No.	**Item Name**	**Unit**	**Initial Cost (SR)**	**Expected Life (SR)**	**Residual (SR)**	**Depreciation**
1	Galvanized iron frame	1	19,200	30	192	634
2	Fans	2	3700	30	37	122
3	Cooling system	10	950	4	0	238
4	Control unit	1	1300	30	0	43
5	Submerged pump	1	700	15	0	47
6	Fiber glass	9	12,150	8	0	1519
7	Irrigation system water pump (1/2 H.P)	1	600	7	12	84
8	Timer	1	500	20	0	25
9	Drip irrigation	1	500	5	0	100
10	Pots	32	352	5	0	70
11	Solenoid valve	1	75	3	0	25
12	Owner's time (opportunity cost)					500
13	Land rent (opportunity cost)					128
Fixed cost/year						3534
Total Fixed cost/production period						1555
Fixed cost/m^2 ((greenhouse area) 346.5 m^2)						4.4

Table A2. Variable cost for hydroponic soilless cultivation.

Item		
1	Tomato seeds (SR)	105
2	Gravel (SR)	75
3	1/3 Perlite + 1/3 Patmos + Botong soil (SR)	133
4	Filtered Irrigation Water m^3/m^2/(SR)	98
5	Electricity cost (SR)	2
6	Pesticides +fungicides/PP	100
7	Labors + marketing (SR)	50.9
	Total variable cost (SR)	563.9
	Area of production m^2	32 m^2
	Variable cost per m^2 (SR)	17.6
	Tomato Yield/m^2	7.48 Kg
	Price/kg (SR)	6.5 SR

Table A3. Variable cost for conventional soil-based cultivation.

Item		
1	Tomato seeds	105
2	Gravel	150
3	Filtered Irrigation Water m^3/m^2/PP	98
4	Electricity K-Watt/day/greenhouse	2
5	Pesticides + fungicides/PP	100
6	Labors/PP	50.9
	Total	505.9

Table A3. *Cont.*

Item		
	Area of production m^2	32 m^2
	Variable cost per m^2 (SR)	15.8
	Tomato Yield/m^2	8.08 Kg
	Price/kg (SR)	6.5 SR

References

1. Winpenny, J.; Heinz, I.; Koo-Oshima, S. *The Wealth of Waste: The Economics of Wastewater Use in Agriculture*; FAO Water Report no. 35; FAO: Rome, Italy, 2010.
2. Fussy, A.; Papenbrock, J. An Overview of Soil and Soilless Cultivation Techniques—Chances, Challenges and the Neglected Question of Sustainability. *Plants* **2022**, *11*, 1153. [CrossRef] [PubMed]
3. Hooshmand, M.; Albaji, M.; Nasab, S.B.; Ansari, N.A.Z. The effect of deficit irrigation on yield and yield components of greenhouse tomato (Solanum lycopersicum) in hydroponic culture in Ahvaz region, Iran. *Sci. Hortic.* **2019**, *254*, 84–90. [CrossRef]
4. Nederhoff, E.; Stanghellini, C. Water use efficiency of tomatoes. *Pract. Hydroponics Greenh.* **2010**, *115*, 52–59.
5. Lizarraga, A.; Boesveld, H.; Huibers, F.; Robles, C. Evaluating irrigation scheduling of hydroponic tomato in Navarra, Spain. *Irrig. Drain.* **2003**, *52*, 177–188. [CrossRef]
6. Estidama. Soilless Cultivation Systems. 2022. Available online: https://estidamah.gov.sa/en/publications/posters/evaluation-soilless-cultivation-systems (accessed on 5 February 2023).
7. Wahb-Allah, M.A.; Alsadon, A.A.; Ibrahim, A.A. Drought tolerance of several tomato genotypes under greenhouse conditions. *World Appl. Sci. J.* **2011**, *15*, 933–940.
8. Parameshwarareddy, R.; Angadi, S.S.; Biradar, M.S.; Patil, R.H. Water productivity of tomato as influenced by drip irrigation levels and substrates. *J. Pharmacogn. Phytochem.* **2018**, *7*, 1343–1346.
9. Sánchez-Rodríguez, E.; Leyva, R.; Constán-Aguilar, C.; Romero, L.; Ruiz, J. How does grafting affect the ionome of cherry tomato plants under water stress? *Soil Sci. Plant Nutr.* **2014**, *60*, 145–155. [CrossRef]
10. Suvo, T.; Biswas, H.; Jewel, M.; Islam; Khan, M. Impact of substrate on soilless tomato cultivation. *Int. J. Agric. Res. Innov. Technol.* **2017**, *6*, 82–86. [CrossRef]
11. Abdulaziz, A.-H.; Abdulrasoul, A.-O.; Thabet, A.; Hesham, A.-R.; Khadejah, A.; Saad, M.; Abdullah, O. Tomato grafting impacts on yield and fruit quality under water stress conditions. *J. Exp. Biol. Agric. Sci.* **2017**, *5*, S136–S147. [CrossRef]
12. Al-Omran, A.M.; Al-Harbi, A.R.; Wahb-Allah, M.A.; Nadeem, M.; Al-Eter, A. Impact of irrigation water quality, irrigation systems, irrigation rates and soil amendments on tomato production in sandy calcareous soil. *Turk. J. Agric. For.* **2010**, *34*, 59–73. [CrossRef]
13. Naif, G.; Emin, Y.; Perihan, C.A.; Mine, A.; Yaşar, K. Determining of the yield, quality and nutrient content of tomatoes grafted on different rootstocks in soilless culture. *Sci. Res. Essays* **2011**, *6*, 2147–2153. [CrossRef]
14. Cámara-Zapata, J.M.; Brotons-Martínez, J.M.; Simón-Grao, S.; Martinez-Nicolás, J.J.; García-Sánchez, F. Cost–benefit analysis of tomato in soilless culture systems with saline water under greenhouse conditions. *J. Sci. Food Agric.* **2019**, *99*, 5842–5851. [CrossRef] [PubMed]
15. McGee, J. Break-even analysis. In *Wiley Encyclopedia of Management*; John Wiley & Sons: Hoboken, NJ, USA, 2015. [CrossRef]
16. Elmulthum, N.A.; Zeineldin, F.I.; Al-Khateeb, S.A.; Al-Barrak, K.M.; Mohammed, T.A.; Sattar, M.N.; Mohmand, A.S. Water Use Efficiency and Economic Evaluation of the Hydroponic versus Conventional Cultivation Systems for Green Fodder Production in Saudi Arabia. *Sustainability* **2023**, *15*, 822. [CrossRef]
17. Naumann, M.; Karl, R.C.; Truong, C.N.; Jossen, A.; Hesse, H.C. Lithium-ion Battery Cost Analysis in PV-household Application. *Energy Procedia* **2015**, *73*, 37–47. [CrossRef]
18. Uiversity of Ohio. Green House Industry. 2017. Available online: https://u.osu.edu/greenhouse/hydroponic-crop-program-links (accessed on 20 October 2022).
19. Istrate, C. Non-Current Assets Depreciation and Impairment between Legal, Accounting at Tax Rules: Evidence from Romania. *Eufire* **2018**, *2018*, 375. Available online: http://eufire.uaic.ro/wp-content/uploads/2018/12/volum_eufire_2018.pdf (accessed on 15 April 2023).
20. Ullah, I.; Mao, H.; Rasool, G.; Gao, H.; Javed, Q.; Sarwar, A.; Khan, M.I. Effect of Deficit Irrigation and Reduced N Fertilization on Plant Growth, Root Morphology and Water Use Efficiency of Tomato Grown in Soilless Culture. *Agronomy* **2021**, *11*, 228. [CrossRef]