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Use of Rainwater Harvesting from Roofs for Irrigation Purposes in Hydroponic Greenhouse Enterprises

Sedat Boyacı [1], Atılgan Atılgan [2], Joanna Kocięcka [3], Daniel Liberacki [3,*] and Roman Rolbiecki [4]

[1] Department of Biosystems Engineering, Faculty of Agriculture, Kırşehir Ahi Evran University, Kırşehir 40100, Turkey; sedat.boyaci@ahievran.edu.tr
[2] Department of Biosystems Engineering, Faculty of Engineering, Alanya Alaaddin Keykubat University, Antalya 07450, Turkey; atilgan.atilgan@alanya.edu.tr
[3] Department of Land Improvement, Environmental Development and Spatial Management, Faculty of Environmental and Mechanical Engineering, Poznań University of Life Sciences, Piątkowska 94, 60-649 Poznań, Poland; joanna.kociecka@up.poznan.pl
[4] Department of Agrometeorology, Plant Irrigation and Horticulture, Faculty of Agriculture and Biotechnology, Bydgoszcz University of Science and Technology, 85-029 Bydgoszcz, Poland; rolbr@pbs.edu.pl
* Correspondence: daniel.liberacki@up.poznan.pl

Abstract: This study was conducted to determine the irrigation water demand due to solar radiation in high-tech greenhouses using hydroponic systems in Turkey's Mediterranean and continental climates, and to determine the annual water consumption and storage capacity with harvested rainwater. Intensive greenhouse cultivation and the recent increase in modern greenhouse cultivation were important factors in selecting the provinces for the study. The chosen provinces were Antalya and Adana, with a Mediterranean climate, and Afyonkarahisar and Kırşehir, with a continental climate. In this research, depending on the production period, the amount of water consumed per unit of area in greenhouses in Antalya, which has a Mediterranean climate, was determined to be 1173.52 L m^{-2} per yr^{-1}, and in Adana, it was 1109.18 L m^{-2} per yr^{-1}. In the provinces of Afyonkarahisar and Kırşehir, where a continental climate prevails, water consumption was calculated to be 1479.11 L m^{-2} per yr^{-1} and 1370.77 L m^{-2} per yr^{-1}, respectively. Storage volumes for the provinces of Antalya, Adana, Afyonkarahisar and Kırşehir were found to be 438.39 L m^{-2}, 122.71 L m^{-2}, 42.12 L m^{-2} and 43.65 L m^{-2}, respectively. For the provinces of Antalya, Adana, Afyonkarahisar and Kırşehir, the rates of rainwater harvesting and meeting plants' water consumption were calculated to be 80.79%, 54.27%, 27.47% and 25.16%, respectively. In addition, the amount of water fee savings that could be achieved by rainwater harvesting was calculated to be USD 901.3 per yr^{-1} for Antalya, USD 835.3 per yr^{-1} for Adana, USD 247.6 per yr^{-1} for Afyonkarahisar and USD 210.2 per yr^{-1} for Kırşehir. As a result, rainwater harvesting will not only provide economic gain to enterprises but will also be important in reducing the negative effects of irregular rainfall regimes caused by climate change on underground and surface water resources. It was also concluded that enterprises should focus on popularizing rainwater harvesting.

Keywords: greenhouse agriculture; rainwater harvesting; irrigation water; plant water consumption; storage volume

Citation: Boyacı, S.; Atılgan, A.; Kocięcka, J.; Liberacki, D.; Rolbiecki, R. Use of Rainwater Harvesting from Roofs for Irrigation Purposes in Hydroponic Greenhouse Enterprises. *Atmosphere* **2024**, *15*, 884. https://doi.org/10.3390/atmos15080884

Academic Editor: Gianni Bellocchi

Received: 30 April 2024
Revised: 19 July 2024
Accepted: 22 July 2024
Published: 25 July 2024

1. Introduction

The importance and effective use of water, which is one of the most basic requirements for the continuation of vital activities, is gaining importance day by day. Population growth and unscheduled industrialization have accelerated the consumption of existing water resources. However, drought caused by climate change poses a threat to water resources. Factors such as depletion of water resources, rapid population growth and unplanned industrialization increase the tendency towards alternative water resources. The widespread water scarcity for agricultural production, especially in arid/semi-arid environments in the Mediterranean region, has necessitated implementing strategies to increase water use efficiency. In addition to the irregular and unbalanced distribution of precipitation, climate change has significantly impacted the sustainability of agricultural production in these regions [1–3]. Effective management of water resources is key to crops' sustainability and profitability. Therefore, developing new techniques for efficient water management under the influence of climate change is encouraged [4]. Considering that the agricultural sector is one of the activities that demand more water, the scarcity of water resources requires appropriate management and use of the available water [5]. As water scarcity worsens, increasing competition between different productive sectors for this limited resource becomes even more evident. Many regions worldwide will face permanent or seasonal water scarcity conditions due to increasing demand in agriculture and other productive sectors, and the uncertainty of water resources caused by climate change [6]. Agriculture is the largest consumer of freshwater worldwide, with irrigation representing approximately 70% of total water use [7]. Additionally, 40% of the land surface allocated to irrigated agriculture uses water from underground sources [8]. Parker and Brown [9] reported that competition for drinking water has increased in many parts of the world, and groundwater continues to decline in many regions. Furthermore, Parker et al. [10] reported that water conservation has become more important in some regions of Texas, as groundwater resources are depleted. Therefore, using water resources efficiently and sustainably in agricultural activities is essential. One practice that can help increase the availability of water resources for agricultural use is rainwater harvesting (RWH). An ancient technique involves collecting and storing surface runoff for later use [11,12]. Rainwater can be collected from the soil surface or the roofs of different structures such as buildings or greenhouses [13,14]. These systems are presented as an effective way to expand water supply for agricultural use and are widely used during drought [15]. RWH is one of the most efficient and simple ways to reduce water consumption from external sources to meet crops' water requirements [16]. Harvesting rainwater and using it for greenhouse irrigation in arid and semi-arid areas with insufficient water resources are important for sustainability. In greenhouse cultivation, rain gutters and tank volumes must be made in appropriate sizes for the rainwater to be collected from the greenhouse roof [17]. In plant production in open areas, a significant part of the water needed by the plants is met by rainfall. However, in greenhouse production, covering material separates the growing environment from the outside atmosphere. For this reason, all the water requirements of the plants to be grown under cover must be supplied to the plants by artificial means. In modern greenhouses built in recent years, storage structures have been built to collect rainwater falling on the roof. However, if land and water resources are limited in low-technology enterprises, producers face major problems in terms of water resources in cultivation. In this case, irrigation water has to be transported over long distances [18]. However, if the rainwater collected from the greenhouse roof is harvested and stored well, it can irrigate the plants grown in the greenhouse. However, an appropriate storage facility should be constructed for harvested rainwater. Thus, harvested rainwater can be used to grow plants with known water needs in the greenhouse [19]. Water harvesting structures can potentially increase the productivity of arable areas by reducing the risk of crop failure and increasing the yield in arid and semi-arid areas where water deficiency is expected due to insufficient rainfall and the irregular distribution of this rainfall [20].

As seen in the studies conducted by researchers, Pari et al. [21] reported that a flexible water storage system (FWSS) could potentially collect an average of 831.7 m^3 of water per year, mitigating excess water in ditches that can potentially cause flooding, and storing fresh water for irrigation during dry periods. Londra et al. [22] investigated the need for irrigation of tomatoes per 1000 m^2 of greenhouse area in three regions of Crete Island (Greece), with significant greenhouse areas. In the Vrysses study area, covered tanks from 100 to 200 m^3 could meet 95.32% to 100% of the tomatoes' irrigation needs, while uncovered tanks from 100 to 520 m^3 could meet 94.07% to 100% of the irrigation needs. In Palaiochora, covered tanks with sizes from 100 to 276 m^3 per 1000 m^2 of greenhouse area could meet 91.10% to 100% of the tomatoes' irrigation needs, while uncovered tanks of 100 to 227 m^3

could meet 89.05% to 92.95%. Furthermore, in the Moires study area, covered tanks with sizes from 100 to 237 m^3 could meet 89.09 to 100%, while uncovered tanks of 100 to 210 m^3 could meet 87.11% to 91.63% of the tomatoes' irrigation needs. Piemontese et al. [23] stated that rainwater harvesting can help maintain crop production and even increase it by 5% to 100%, depending on the characteristics of the region [24–27], and that the water collected from the greenhouse's surface can be used for tomatoes. They stated that it can meet 30% to 60% of the water needs of crops such as cucumbers or peppers.

In greenhouse systems, knowledge of plants' water and nutrient uptake is crucial for the development of sustainable strategies that optimally support plant growth [28]. Compared with some alternative strategies, conventional agriculture consumes large amounts of fresh water and fertilizer for comparatively low yields [29]. Soilless cultivation represents a valid opportunity for agricultural production, especially in areas with severe soil degradation and limited water availability [30]. The soilless culture system is a promising, intensive and sustainable approach with several advantages for crop production [31]. Soilless culture has various classification systems and methods, such as hydroponics, aeroponics and aquaponics [32]. Hydroponics is a plant-growing technique in which plants can be grown in nutrient solutions (containing dissolved plant nutrients) and without soil (soilless culture), with or without mechanical support such as sand, gravel, vermiculite, rockwool, perlite, peat moss, coconut fibers or sawdust [33,34]. Hydroponics involves the cultivation of crops such as vegetables, flowers and herbs without soil [35]. This system supports high-yield production per unit of area and food production in limited areas, is less labor-intensive, conserves water and allows for the cultivation of annual crops [33,36]. Irrigation for hydroponics in high-tech greenhouses established in recent years in Turkey is planned according to the intensity of solar radiation. According to the intensity of solar radiation in hydroponic culture, the plan for normal irrigation is one application of irrigation per 80 J cm^{-2}. In this method, plants can be directed to the desired growth characteristics by reducing or increasing the irrigation intervals [37]. In a study by Ntinas et al. [38] comparing soil-based greenhouse cultivation in Germany with hydroponic agriculture in Greece, they stated that soilless agriculture saved a significant amount of water, 458.4 L m^{-2} and 216.1 L m^{-2}. Additionally, Gartmann et al. [39] and Massa et al. [40] reported that the transition to a closed-loop system in soilless agriculture significantly reduced nitrate pollution of water resources. They also noted that recycling the nutrient solution optimized water and fertilizer use.

In this study, the water consumption required for tomato production was determined in the case of irrigation according to the intensity of solar radiation in greenhouses with hydroponic systems located in four different provinces of Turkey with Mediterranean and continental climates. In addition, this experiment aimed to calculate the water consumed by rainwater harvesting, determine the storage capacity and estimate the harvested rainwater's rates of meeting the water consumption needs.

2. Materials and Methods

2.1. Study Area

In this study, four provinces of Turkey with different climates were considered to evaluate the use of rainwater that could be stored on the greenhouse roof as irrigation water in hydroponic greenhouses. The provinces of Antalya and Adana, which have a Mediterranean climate and greenhouse cultivation is expected, are important greenhouse centers in the south of Turkey. These provinces have the largest concentration of greenhouses in Turkey. Due to the ecological characteristics of these provinces, heating costs are low in winter and greenhouses are left empty in July and August due to high temperatures in summer. In addition, the province of Afyonkarahisar, which has a continental climate and is located in the west of Turkey, and the province of Kırşehir, located in the Central Anatolia region, were included in the study. The area and production are increasing day by day in the provinces of Afyonkarahisar and Kırşehir, where geothermal resources have begun to be used for heating greenhouses. Since the heating costs of geothermal resources are low and the temperatures in the summer months are lower than in Antalya and Adana, producing throughout the year in these provinces is possible. In these four provinces, greenhouse cultivation of tomato is dominant in both area and production amounts. In addition, high-tech greenhouses have increased dramatically in recent years in these provinces. Consequently, on the basis of the abovementioned data for the development of greenhouse agriculture in Turkey, four different provinces were selected as the study area, and the possibilities of using rainwater harvesting in greenhouses with hydroponic agriculture were investigated. The greenhouse agricultural areas of the provinces are given in Table 1 [41].

Table 1. Greenhouse agricultural areas of the provinces.

Greenhouse Agriculture Areas	Turkey	Antalya	Adana	Afyonkarahisar	Kırşehir
Low tunnel, da	169,538.3	11,984.0	97,196.0	-	6.0
High tunnel, da	110,426.5	17,106	22,637.2	158	32.0
Plastic greenhouse, da	471,283.9	238,764	7042.0	1859	1710.0
Glass greenhouse, da	59,632.8	43,188.2	2.0	135	-
Total	810,881.5	311,042.2	126,877.2	2152.0	1748.0

The province of Antalya, which has a Mediterranean climate, constitutes 38.4% of the total greenhouse area in Turkey; the province of Adana constitutes 15.6%; Afyonkarahisar, which has a continental climate, constitutes 0.3% and the province of Kırşehir constitutes 0.2%. Tomatoes are the most widely grown among the products grown under greenhouse cultivation in Turkey. Turkey's production of table tomatoes is 4,139,337 tons; production is 2,528,291 tons in the province of Antalya (61.1%), 36,826 tons in the province of Adana (0.9%), 109,131 tons in the province of Afyonkarahisar (2.6%) and 8128 tons in the province of Kırşehir (0.2%).

2.2. Evaluation of the Provinces in Terms of Precipitation and Solar Radiation

The province of Antalya is located in the Mediterranean region of Turkey at latitude 36.9081 N and longitude 30.6956 E, and its altitude is 39 m. The province of Adana is at latitude 36.9914 N and longitude 35.3308 E, and its altitude is 23 m. The province of Afyonkarahisar in the Aegean Region is at latitude 38.756886 N and longitude 30.538704 E, and its altitude is 1034 m. The province of Kırşehir, located in the Central Anatolia region, is at latitude 39.1639 N and longitude 34.1561 E, and its altitude is 1007 m.

The values of monthly average precipitation and solar radiation between 1930 and 2023 provided by the General Directorate of Meteorology for provinces in different climate zones are given in Table 2 [42].

The total annual precipitation in the provinces of Antalya and Adana, which are located in the south of Turkey and have a Mediterranean climate, is 1053.40 and 668.80 mm m^{-2} $month^{-1}$, respectively. Furthermore, it is 451.40 mm m^{-2} $month^{-1}$ in the province of Afyonkarahisar, which has a continental climate and is located in the west, and 383.20 mm m^{-2} $month^{-1}$ in the province of Kırşehir, located in Central Anatolia. It can be seen that the amount of precipitation in the provinces of Afyonkarahisar and Kırşehir is lower than that in the provinces of Antalya and Adana. The value of average radiation is 1623.9 in Antalya and 1543.2 J cm^{-2} in Adana. In the provinces of Afyonkarahisar and Kırşehir, it is 1506.6 and 1489.2 J cm^{-2}, respectively. In this case, while the amount of irrigation to be given to the plant increases depending on the values of radiation in the regions with a Mediterranean climate, the possibility of harvesting rainwater is high due to the high amount of rainfall. However, in provinces with a continental climate, due to the high values of radiation, the amount of irrigation to be given to the plant will be high but the amount of rainwater that can be harvested will be low.

Table 2. Monthly changes in the average precipitation and radiation values of the provinces.

Months	Antalya		Adana		Afyonkarahisar		Kırşehir	
	Precipitation, mm m^{-2} $month^{-1}$	Radiation, J cm^{-2}	Precipitation, mm m^{-2} $month^{-1}$	Radiation, J cm^{-2}	Precipitation, mm m^{-2} $month^{-1}$	Radiation, J cm^{-2}	Precipitation, mm m^{-2} $month^{-1}$	Radiation, J cm^{-2}
January	234.50	763.2	113.60	712.8	46.90	666.0	48.30	640.8
February	150.20	925.2	89.00	871.2	38.40	889.2	35.20	856.8
March	92.10	1573.2	65.50	1483.2	44.60	1440.0	39.60	1400.4
April	49.00	1969.2	51.00	1792.8	47.00	1836.0	41.00	1738.8
May	34.30	2289.6	48.10	2185.2	50.10	2235.6	44.30	2192.4
June	11.00	2494.8	22.10	2404.8	41.50	2386.8	34.60	2329.2
July	4.40	2394.0	10.20	2325.6	21.80	2059.2	8.30	2311.2
August	4.30	2210.4	9.30	2127.6	18.00	2138.4	7.90	2106
September	16.90	1857.6	19.30	1764.0	23.60	1771.2	13.00	1742.4
October	70.90	1414.8	42.80	1360.8	40.30	1270.8	26.20	1234.8
November	129.70	903.6	71.50	838.8	32.40	788.4	36.30	748.8
December	256.10	691.2	126.40	651.6	46.80	597.6	48.50	568.8

2.3. Determination of Crop Water Requirements

Daily water consumption in greenhouses with hydroponic agriculture was determined according to the intensity of solar radiation. Transpiration is the process of water moving through a plant and essentially evaporating from its leaves. The difference between the water given in the substrate for cultivation and the water drained is the amount of water the plants use for transpiration. We calculated daily crop water requirements by month on the values given in Equation (1).

$$CWR_{\mathrm{d}} = \frac{(SR \times TT) \times (1 + DT)}{1000} \tag{1}$$

In the equation, CWR_{d} is the daily crop water requirement (L m^{-2} day^{-1}), SR is the solar radiation (J cm^{-2}), TT is the transpiration target (mL J^{-1}) and DT is the drainage target (%).

In determining crops' water requirements, the transpiration target was taken to be 2 mL J^{-1} and the drainage target was 30% for a value of radiation of 1 J cm^{-2}.

2.4. Determining the Storage Pool's Capacity

Daily values of rainfall were used to determine the accurate rainwater storage capacity. However, since these values are not known for many areas, monthly rainfall amounts were used in this study in order to determine the storage capacity [37]. The monthly amount of rainwater that can be stored was calculated with Equation (2) [43].

$$CV_{\mathrm{m}} = Pre \times R_{\mathrm{c}} \tag{2}$$

In this equation, CV_m is the amount of water harvested (L m^{-2} $month^{-1}$), R_C is the rate of water harvesting (%) and Pre is the monthly precipitation (mm $month^{-1}$). The R_C value was taken to be 90% in the calculations. Storable monthly rainfall was calculated with the help of Equation (3).

$$STP_{\mathrm{m}} = CV_{\mathrm{m}} - CWR_{\mathrm{m}} - EV_{\mathrm{pond}} \tag{3}$$

In this equation, STP_{m} is the monthly stored rainfall (L m^{-2} $month^{-1}$), CWR_{m} is the monthly crop water requirement (L m^{-2} $month^{-1}$) and EV_{pond} is the evaporation losses from the storage pool (L m^{-2} $month^{-1}$).

In the calculations, evaporation losses from the storage pool were taken to be 0, assuming that the pool's surface is covered with PE plastic. As a result of the calculations, when the monthly amount of storable precipitation (STP_{m}) was positive, the pool was filled, and when STP_{m} was negative, the water in the pool decreased.

Storable annual precipitation depending on the stored monthly rainfall was determined with Equation (4).

$$STP_{\mathrm{y}} = \sum(+)STP_{\mathrm{m}} \tag{4}$$

The annual deficit due to the plants' water consumption was calculated with Equation (5).

$$DEF_{\mathrm{y}} = \sum(-)STP_{\mathrm{m}} \tag{5}$$

The amount of stored annual precipitation was calculated with Equation (6).

$$STB_{\mathrm{y}} = STP_{\mathrm{y}} - DEF_{\mathrm{y}} \tag{6}$$

In determining the storage capacity, the following conditions were taken into account [37,43].

1. When $STB_{\mathrm{y}} > 0$ or $STP_{\mathrm{y}} > DEF_{\mathrm{y}}$, the amount of stored water will meet the plants' water needs during the production period. In this case, the storage capacity should be considered to be $VST = DEF_{\mathrm{y}}$ (L m^{-2}).

When the changes in precipitation over the months are large, the storage volume should be increased. In this case, the storage volume should be $VST = DEF_{\mathrm{y}}\ (1 + V_{\mathrm{C}})$(L m^{-2}).

2. If $STB_{\mathrm{y}} < 0$ or $STP_{\mathrm{y}} < DEF_{\mathrm{y}}$, the stored rainfall is insufficient for irrigation. In this case, two conditions must be considered:
   (a) If the amount of stored rainfall is greater than the monthly maximum rainfall collected ($STP_{\mathrm{y}} > CV_{\mathrm{mmax}}$), then the storage volume should be VST = $\mathrm{STP_y}$, and when the variation in precipitation over the months is large, it should be determined as $VST = STP_{\mathrm{y}}\ (1 + \mathrm{V_C})$.
   (b) If the amount of stored rainfall is less than the monthly maximum rainfall collected ($STP_{\mathrm{y}} < CV_{\mathrm{mmax}}$), then the storage volume should be $VST = CV_{\mathrm{mmax}}$, and when the variation in precipitation over the months is large, it should be determined as $VST = CV_{\mathrm{mmax}}\ (1 + \mathrm{V_C})$.

3. Results and Discussion

3.1. Determining the Ratio of Rainwater Harvesting to Meet Plants' Water Consumption and Storage Capacity

The storage structures needed to collect harvested rainwater must be built in appropriate sizes. In order to determine the volume of the storage structure to be planned, it is necessary first to determine the water consumption of the plants and the amount of water that can be gained from precipitation. Production in greenhouses in the province of Antalya starts in the last week of August and continues until the end of June. The required storage capacities and the amount of rainwater that can be harvested according to the calculated amount of water consumption in the production period, depending on the monthly rainfall and daily total radiation intensities of the province of Antalya, are given in Table 3.

According to Table 3, the highest rainfall in the province of Antalya's climate conditions is in December, and the total annual rainfall is 1053.4 mm. Considering that 90% of the precipitation falling on the greenhouse cover's surface is harvested, the amount of precipitation that can be stored is 948.06 mm m^{-2} yr^{-1}. The change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in Antalya is given in Figure 1.

Table 3. Change in the amount of water consumption depending on daily total intensity of radiation of the province of Antalya.

Months	Precipitation, mm m^{-2} month^{-1}	*CV*m, mm m^{-2} month^{-1}	dm	*CWR*d, L m^{-2} day^{-1}	*CWR*m, L m^{-2} month^{-1}	*STP*m, L m^{-2} month^{-1}	*STP* Accumulated, L m^{-2} month^{-1}	*IW*, L m^{-2}
January	234.50	211.05	31	1.98	61.51	149.54	370.56	0.00
February	150.20	135.18	28	2.41	67.35	67.83	438.39	0.00
March	92.10	82.89	31	4.09	126.80	−43.91	394.48	0.00
April	49.00	44.10	30	5.12	153.60	−109.50	284.98	0.00
May	34.30	30.87	31	5.95	184.54	−153.67	131.31	0.00
June	11.00	9.90	30	6.49	194.59	−184.69	−53.38	53.38
July	4.40	3.96	31	6.22	0.00	3.96	3.96	0.00
August	4.30	3.87	31	5.75	0.00	3.87	7.83	0.00
September	16.90	15.21	30	4.83	144.89	−129.68	−121.85	121.85
October	70.90	63.81	31	3.68	114.03	−50.22	−172.08	50.22
November	129.70	116.73	30	2.35	70.48	46.25	46.25	0.00
December	256.10	230.49	31	1.80	55.71	174.78	221.03	0.00
Total	1053.40	948.06			1173.52			225.46

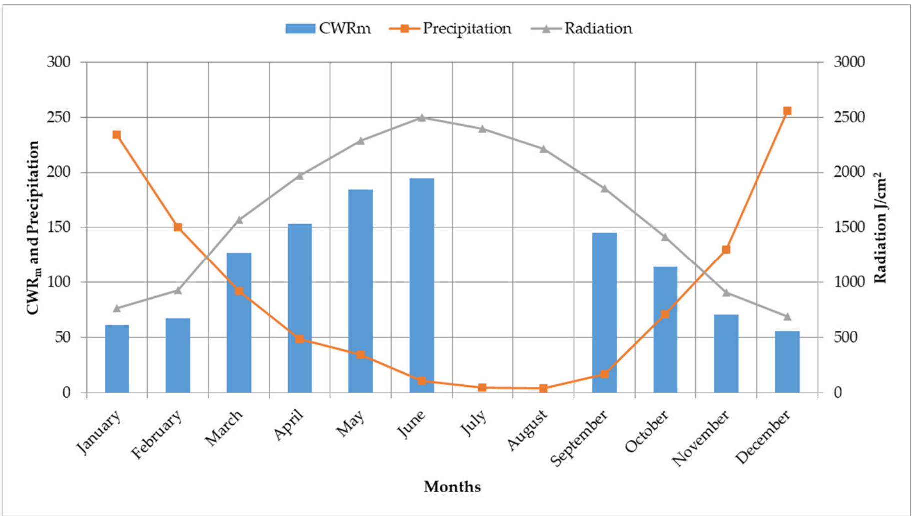

Figure 1. Change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Antalya.

Considering that greenhouse cultivation starts in the last week of August and ends in the end of June in the climate conditions of the province of Antalya, which has a Mediterranean climate, 7.83 L of water can be stored by collecting precipitation in July and August. Assuming that 90% (15.21 L) of the precipitation in September is collected and 7.83 L m^{-2} of water kept in the tanks is used, only 15.90% of the 144.89 L of water needed in September will be met by precipitation. The remaining amount of irrigation water needed in September (129.68 L) must be met from different sources. While the amount of irrigation required on the basis of solar radiation decreases in October, the amount of irrigation water needed from external sources is 50.22 L with the increase in precipitation. Under the climatic conditions of the province of Antalya, rainwater collection begins in November. As can be seen in Table 3, the amount of irrigation water needed due to the decrease in solar radiation in November is 70.48 L, and the amount of rainwater collected is 116.73 L. Under these conditions, the remaining 46.25 L of the collected precipitation can be stored. Suppose 90% of the rainfall in Antalya is collected after November. In that case, it is possible to meet the irrigation water requirements in the greenhouse without water from external sources until the end of May. In order to size the tanks to be established to store rainwater, the volumes calculated according to the amount of monthly rainfall and water consumption must be known. Table 3 gives the storage volumes calculated depending on monthly precipitation and the plants' water needs under Antalya's climate conditions. As can be seen from the calculations, if 90% of the rainwater is harvested, the highest storage volume occurs in February, with 438.39 L m^{-2} month^{-1}. Under Antalya's climate conditions, when 90% of the precipitation (948.06 L m^{-2}) is harvested, 80.79% of the annual water consumption (1173.52 L m^{-2}) can be met. Accordingly, 19.21% of the water needed must be met from external sources.

Production in greenhouses in the province of Adana starts in the last week of August and continues until the end of June. The required storage capacities and the amount of rainwater that can be harvested according to the calculated amount of water consumption in the production period, depending on the monthly precipitation and daily total intensity of radiation of the province of Adana, are given in Table 4.

Table 4. Changes in the amount of water consumption depending on the daily total intensity of radiation of the province of Adana.

Months	Precipitation, mm m^{-2} month^{-1}	*CV*m, mm m^{-2} month^{-1}	dm	*CWR*d, L m^{-2} day^{-1}	*CWR*m, L m^{-2} month^{-1}	*STP*m, L m^{-2} month^{-1}	*STP* Accumulated, L m^{-2} month^{-1}	*IW*, L m^{-2}
January	113.60	102.24	31	1.85	57.45	44.79	106.03	0.00
February	89.00	80.10	28	2.27	63.42	16.68	122.71	0.00
March	65.50	58.95	31	3.86	119.55	−60.60	62.11	0.00
April	51.00	45.90	30	4.66	139.84	−93.94	−31.83	31.83
May	48.10	43.29	31	5.68	176.13	−132.84	−164.67	132.84
June	22.10	19.89	30	6.25	187.57	−167.68	−332.35	167.68
July	10.20	9.18	31	6.05	0.00	9.18	9.18	0.00
August	9.30	8.37	31	5.53	0.00	8.37	17.55	0.00
September	19.30	17.37	30	4.59	137.59	−120.22	−102.67	102.67
October	42.80	38.52	31	3.54	109.68	−71.16	−173.83	71.16
November	71.50	64.35	30	2.18	65.43	−1.08	−174.91	1.08
December	126.40	113.76	31	1.69	52.52	61.24	61.24	0.00
Total	668.80	601.92			1109.18			507.26

According to Table 4, the month with highest rainfall in the climate conditions of Adana is December, and the total annual rainfall is 668.80 mm. Considering that 90% of the precipitation falling on the greenhouse cover's surface is harvested, the amount of precipitation that can be stored is 601.92 mm m^{-2} yr^{-1}. The change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in Adana is given in Figure 2.

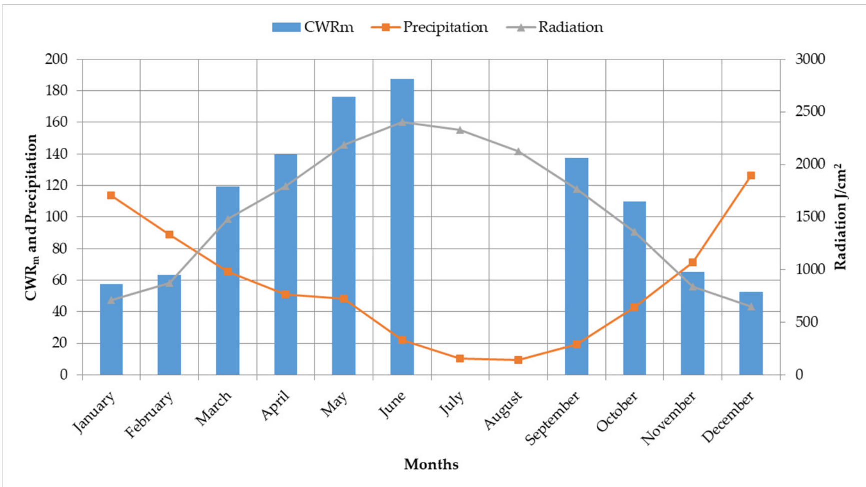

Figure 2. Changes in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Adana.

Considering that greenhouse cultivation starts in the last week of August and ends at the end of June in the climate conditions of the province of Adana, 17.55 L of water can be stored by collecting precipitation in July and August. Assuming that 90% (17.37 L) of the precipitation in September is collected and 17.55 L m^{-2} of water kept in the tanks is used, only 25.38 1% of the 137.59 L of the water needed in September will be met by precipitation. The remaining irrigation water needed in September (120.22 L) must be obtained from different sources. While the amount of irrigation required according to the solar radiation decreases in October, the amount of irrigation water needed from external sources is 71.16 L with increased precipitation. Under Adana's climate conditions, rainwater collection begins in December. As can be seen in Table 3, the amount of irrigation water needed due to the decrease in solar radiation in December is 52.52 L, and the amount of rainwater collected is 113.76 L. Under these conditions, the remaining 61.24 L of the collected precipitation can be stored. Suppose 90% of the rainfall in Adana is collected after December. In that case, it is possible to take irrigation water in the greenhouse without the need for an external water supply until the end of March. In order to size the tanks to be established to store rainwater, the volumes calculated according to the monthly amount of rainfall and water consumption must be known. Table 4 presents the storage volumes based on monthly precipitation and the plants' water needs under Adana's climate conditions. As can be seen from the calculations, if 90% of the rainwater is harvested, the highest storage volume occurs in February, with 122.71 L m^{-2} month^{-1}. In Adana's climate conditions, when 90% of the precipitation (601.92 L m^{-2}) is harvested, only 54.27% of the annual water consumption (1109.18 L m^{-2}) can be met. Accordingly, 45.73% of the water needed must be obtained from external sources.

Greenhouse production continues year-round in the province of Afyonkarahisar, which is located in the Aegean region and has geothermal resources. The required storage capacities and the amount of rainwater that can be harvested according to the amount of water consumption calculated during the production period, depending on the monthly precipitation and daily total intensity of radiation in the province of Afyonkarahisar, are given in Table 5.

Table 5. Change in the amount of water consumption depending on daily total intensity of radiation in the province of Afyonkarahisar.

Months	Precipitation, mm m^{-2} month^{-1}	*CV*m, mm m^{-2} month^{-1}	dm	*CWR*d, L m^{-2} day^{-1}	*CWR*m, L m^{-2} month^{-1}	*STP*m, L m^{-2} month^{-1}	*STP* Accumulated, L m^{-2} month^{-1}	*IW*, L m^{-2}
January	46.90	42.21	31	1.85	57.35	−15.14	26.98	0.00
February	38.40	34.56	28	2.47	69.16	−34.60	−7.62	7.62
March	44.60	40.14	31	4.00	124.00	−83.86	−91.48	83.86
April	47.00	42.30	30	5.10	153.00	−110.70	−202.18	110.70
May	50.10	45.09	31	6.21	192.51	−147.42	−349.60	147.42
June	41.50	37.35	30	6.63	198.90	−161.55	−511.15	161.55
July	21.80	19.62	31	5.72	177.32	−157.70	−668.85	157.70
August	18.00	16.20	31	5.94	184.14	−167.94	−836.79	167.94
September	23.60	21.24	30	4.92	147.60	−126.36	−963.15	126.36
October	40.30	36.27	31	3.53	109.43	−73.16	−1036.31	73.16
November	32.40	29.16	30	2.19	65.70	−36.54	−1072.85	36.54
December	46.80	42.12	31	1.66	0.00	42.12	42.12	0.00
Total	451.40	406.26			1479.11			1072.85

In Afyonkarahisar's climate conditions, the most precipitation occurs in January, and the total annual precipitation is 451.4 mm. Considering that 90% of the precipitation falling on the greenhouse cover's surface is harvested, the amount of precipitation that can be stored is 406.26 mm m^{-2} yr^{-1}. The change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Afyonkarahisar is given in Figure 3.

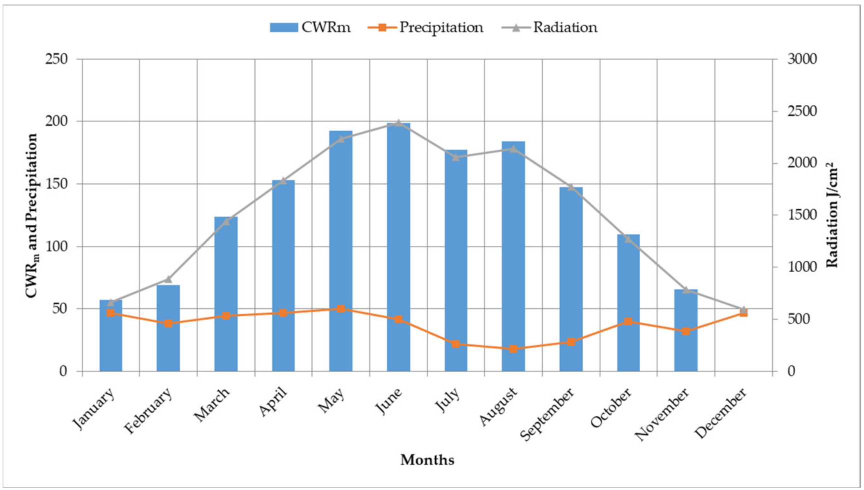

Figure 3. Change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Afyonkarahisar.

Considering that greenhouse cultivation in Afyonkarahisar's climate conditions starts in the last week of December and ends in the first week of December, 42.12 L of water can be stored by collecting precipitation in December. Assuming that 90% (42.21 L) of the precipitation in January is collected and 42.12 L m^{-2} of water kept in the tanks is used, all (100%) of the 57.35 L water needed in January will be met by precipitation. Assuming that 26.98 L of water in the tank and 34.56 L of the water supplied by rain are used in February, 88.98% of the 69.16 L of water needed in February will be met by rain. The remaining amount of irrigation water needed in February (7.62 L) must be obtained from different sources. As can be seen from the calculations made in Table 5 for Afyonkarahisar, where the amount of rainfall is low, irrigation water is not needed only in December and January when planting is carried out, so it is possible to store rainfall this month. Accordingly, 42.12 L m^{-2} of storage capacity is sufficient to store the precipitation in December. In Afyonkarahisar's climate conditions, when 90% of the precipitation (406.26 L m^{-2}) is harvested, only 27.47% of the annual water consumption (1479.11 L m^{-2}) can be provided. Accordingly, 72.53% of the water needed must be supplied from external sources.

Production in greenhouses continues all year round in the province of Kırşehir, which has geothermal resources. The required storage capacities and the amount of rainwater that can be harvested according to the calculated amount of water consumption in the production period, depending on the monthly precipitation and daily total intensity of radiation of the province of Kırşehir, are given in Table 6.

Table 6. Change in the amount of water consumption depending on daily total intensity of radiation of the province of Kırşehir.

Months	Precipitation, mm m^{-2} month^{-1}	*CV*m, mm m^{-2} month^{-1}	dm	*CWR*d, L m^{-2} day^{-1}	*CWR*m, L m^{-2} month^{-1}	*STP*m, L m^{-2} month^{-1}	*STP* Accumulated, L m^{-2} month^{-1}	*IW*, L m^{-2}
January	48.30	43.47	31	1.67	51.65	−8.18	35.47	0.00
February	35.20	31.68	28	2.23	62.38	−30.70	4.78	0.00
March	39.60	35.64	31	3.64	112.87	−77.23	−72.46	72.46
April	41.00	36.90	30	4.52	135.63	−98.73	−171.18	98.73
May	44.30	39.87	31	5.70	176.71	−136.84	−308.02	136.84
June	34.60	31.14	30	6.06	181.68	−150.54	−458.56	150.54
July	8.30	7.47	31	6.01	186.28	−178.81	−637.37	178.81
August	7.90	7.11	31	5.48	169.74	−162.63	−800.00	162.63
September	13.00	11.70	30	4.53	135.91	−124.21	−924.21	124.21
October	26.20	23.58	31.	3.21	99.52	−75.94	−1000.16	75.94
November	36.30	32.67	30	1.95	58.41	−25.74	−1025.89	25.74
December	48.50	43.65	31	1.48	0.00	43.65	43.65	0.00
Total	383.20	344.88			1370.77			1025.89

In Kırşehir's climate conditions, the most precipitation occurs in December, and the total annual precipitation is 383.2 mm. Considering that 90% of the precipitation falling on the greenhouse cover's surface is harvested, the amount of precipitation that can be stored is 344.88 mm m^{-2} yr^{-1}. The change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Kırşehir is given in Figure 4.

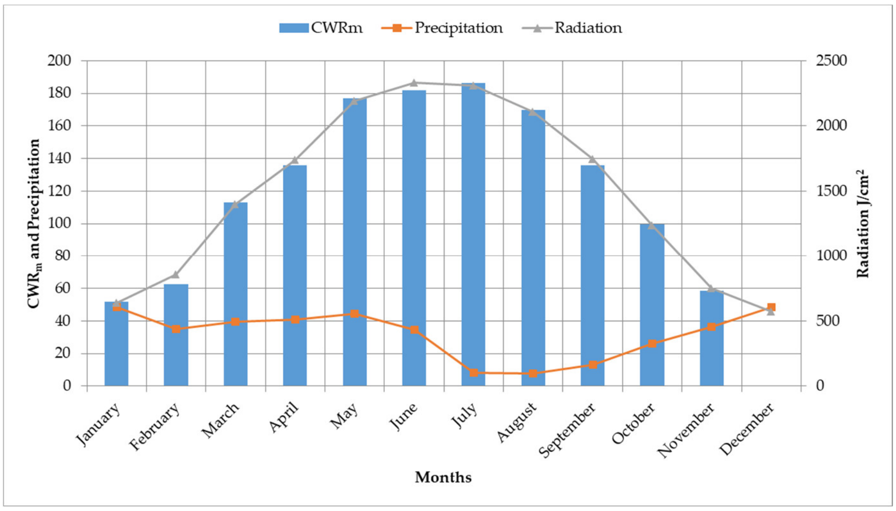

Figure 4. Change in the amount of monthly water consumption in the greenhouse according to monthly rainfall and the intensity of solar radiation in the province of Kırşehir.

Since greenhouse cultivation starts in the last week of December in Kırşehir's climate conditions and ends in the first week of December, 43.65 L of water can be stored by collecting precipitation in December. Assuming that 90% (43.47 L) of the precipitation in January is collected and 43.65 L m^{-2} of water kept in tanks is used, all (100%) of the 51.65 L water needed in January will be met by precipitation. Moreover, assuming that 4.78 L of water in the tank and 35.64 L of the water supplied by rain are used in March, 35.81% of the 112.87 L water needed in March will be met by rains. The remaining amount of irrigation water needed in March (72.46 L) must be obtained from different sources. As can be seen from the calculations in Table 6 for Kırşehir, where the amount of rainfall is low, irrigation water is not needed only in December, when planting is carried out, so storing rainfall in this month is possible. Accordingly, 43.65 L m^{-2} of storage capacity is sufficient to store the rainfall in December. In Kırşehir's climate conditions, when 90% of the precipitation (344.88 L m^{-2}) is harvested, only 25.16% of the annual water consumption (1370.77 L m^{-2}) can be met. Accordingly, 74.84% of the water needed must be supplied from external sources.

In many regions, there is a surplus of water to irrigate plants during the rainy seasons, while a water deficit occurs during the dry seasons. For plants grown in greenhouses during rainy periods, rainwater flowing from the roofs of the greenhouses can be harvested and used for irrigation. Additionally, saline irrigation water can be used after mixing with rainwater. For this purpose, greenhouses with sufficiently large water troughs and tanks must be built to harvest rainwater. In order to calculate the storage for rainwater and irrigation systems, it is necessary to know the irrigation water requirements of the plant to be grown [43]. Looking at the studies conducted by the researchers Singh et al. [27], in the Ludhiana region (India), where the average annual rainfall is 781.5 mm, 60% of the irrigation water needs of pepper plants can be met with a 125 m^3 tank in a greenhouse with a floor area of 560 m^2, and if the floor area is between 560–4000 m^2, a storage tank can be used. They reported that its capacity will vary across 125–892 m^3. Londra et al. [44] examined the reliability of rainwater tanks for meeting the irrigation needs of begonia and tomato crops in two regions of Greece with low annual rainfall (419 mm and 448 mm). In the study, they found that 65–72% of the irrigation needs of the begonia plants during a 12-month growing season could be met with closed tanks of 100 to 200 m^3 per 1000 m^2 of greenhouse area, and 90–100% of the irrigation needs of the tomato plants during the 8-month growing period could be met with closed tanks of 100–290 m^3 per 1000 m^2 of greenhouse area. They also reported that the affordability with open tanks was 91%, with a critical tank capacity of 177 m^3 for a greenhouse area of 1000 m^2. Boyacı and Kartal [25] found that 61.49% of the irrigation water to be given to tomato plants in a greenhouse without heating between April and September in the province of Kırşehir (Turkey) and 47.74% of the total irrigation water need in the case that the greenhouse was heated throughout the year, was rainwater. It has been reported that this can be met by harvesting. Additionally, it has been stated that the storage capacity can be met with tanks with a capacity of 0.21 and 0.30 m^3/m^2 in heated and unheated greenhouses, respectively. Boyaci and Kartal [26] determined the plants' daily amount of water consumption depending on the month in greenhouses that are not heated regularly in Kumluca district of the province of Antalya (Turkey) according to the FAO's Penman–Monteith method. The results obtained in that study determined that it was possible to meet all of the needed for irrigation water to be given to the plant by rainwater harvesting during the periods between September and June, when single-crop tomato cultivation was carried out in the province, where the annual rainfall was 734.44 L m^{-2}, and that a storage volume of 0.40 m^3 m^{-2} was needed in the greenhouse. Baytorun et al. [18] found that the methods that provided the most appropriate value of plant water consumption according to the climatic conditions of Mersin (Turkey) are the FAO-Radiation and the FAO's Blaney-Criddle methods. Scientists commonly use these methods to assess plants' water needs [45,46]. Moreover, using the water consumption and rainfall calculated according to the FAO-Radiation method, the storage capacity is 0.25 m^3 m^{-2} and the amount of water harvested from the greenhouse roof can meet the plants' water needs for 7 months between November and May. According to the FAO's Blaney-Criddle method, it was determined that the storage capacity was 0.19 m^3 m^{-2} and that plants' water consumption could be met for 6 months in the period between November and April. In the study conducted by Baytorun et al. [37] to determine the irrigation water needed due to solar radiation in high-tech greenhouses with soilless agriculture according to TS825 standards and to determine the annual water consumption and storage capacity with harvested rainwater, as a result of the calculations made for the western Mediterranean region, it was found that if 90% of the rainfall was harvested in the Mediterranean region, 72% of the annual water consumption could be met, and 45% in the eastern Mediterranean region. In the inner regions where the continental climate prevails, 22–32% of the annual water consumption could be met with 90% of the harvested rain, depending on the amount of precipitation. They calculated the required storage volume to be 0.420 m^3 m^{-2} in the western Mediterranean region, 0.096 m^3/m^2 in the eastern Mediterranean region and 0.044 m^3 m^{-2} in Kırşehir, where the continental climate prevails. Ertop et al. [13] The amount of water that can be obtained from rain harvesting from greenhouses in Antalya, which has approximately half of the greenhouses in Turkey, is 224,992,795.8 m^3 annually. Monthly calculations throughout the year showed that the least water could be collected in August (938,447.53 m^3) and the most (54,771,210 m^3) in December. For this reason, they stated that some of the plants' water consumption needs can be met by adequate storage in areas close to the greenhouse.

3.2. Economic Savings from Rainwater Harvesting and Irrigation Water Fees

In the study, the amount of water consumed by plants for the provinces of Antalya and Adana, the water fees corresponding to the amount of harvested rainwater and the savings that can be obtained from harvested rainwater are given in Tables 7 and 8.

Table 7. Amounts of savings that can be obtained from rainwater harvesting for the provinces of Antalya and Adana.

Months	Antalya				Adana			
	CWR_m, m^3	Water Fee, USD	CV_m, m^3	Fee Savings, USD	CWR_m, m^3	Water Fee, USD	CV_m, m^3	Fee Savings, USD
January	3075.7	37.5	10,552.5	128.6	2872.6	35.0	5112.0	62.3
February	3367.7	41.0	6759.0	82.4	3171.2	38.6	4005.0	48.8
March	6340.0	77.3	4144.5	50.5	5977.3	72.8	2947.5	35.9
April	7679.9	93.6	2205.0	26.9	6991.9	85.2	2295.0	28.0
May	9227.1	112.5	1543.5	18.8	8806.4	107.3	2164.5	26.4
June	9729.7	118.6	495.0	6.0	9378.7	114.3	994.5	12.1
July	0.0	0.0	198.0	2.4	0.0	0.0	459.0	5.6
August	0.0	0.0	193.5	2.4	0.0	0.0	418.5	5.1
September	7244.6	88.3	760.5	9.3	6879.6	83.8	868.5	10.6
October	5701.6	69.5	3190.5	38.9	5484.0	66.8	1926.0	23.5
November	3524.0	42.9	5836.5	71.1	3271.3	39.9	3217.5	39.2
December	2785.5	33.9	11,524.5	140.5	2625.9	32.0	5688.0	69.3
Total	58,676.0	715.1	47403.0	577.7	55,458.9	675.9	30,096.0	366.8

Table 8. Amount of savings that can be obtained from rainwater harvesting for the provinces of Afyonkarahisar and Kırşehir.

Months	Afyonkarahisar				Kırşehir			
	CWR_m, m^3	Water Fee, USD	CV_m, m^3	Fee Savings, USD	CWR_m, m^3	Water Fee, USD	CV_m, m^3	Fee Savings, USD
January	2867.5	34.9	2110.5	25.7	2582.4	31.5	2173.5	26.5
February	3458.0	42.1	1728.0	21.1	3118.8	38.0	1584.0	19.3
March	6200.0	75.6	2007.0	24.5	5643.6	68.8	1782.0	21.7
April	7650.0	93.2	2115.0	25.8	6781.3	82.6	1845.0	22.5
May	9625.5	117.3	2254.5	27.5	8835.4	107.7	1993.5	24.3
June	9945.0	121.2	1867.5	22.8	9083.9	110.7	1557.0	19.0
July	8866.0	108.1	981.0	12.0	9314.1	113.5	373.5	4.6
August	9207.0	112.2	810.0	9.9	8487.2	103.4	355.5	4.3
September	7380.0	89.9	1062.0	12.9	6795.4	82.8	585.0	7.1
October	5471.5	66.7	1813.5	22.1	4976.2	60.6	1179.0	14.4
November	3285.0	40.0	1458.0	17.8	2920.3	35.6	1633.5	19.9
December	0.0	0.0	2106.0	25.7	0.0	0.0	2182.5	26.6
Total	73,955.5	901.3	20,313.0	247.6	68,538.6	835.3	17,244.0	210.2

If the water needed in the greenhouse is taken from an external source with pressurized irrigation, the irrigation fee is USD 0.012 m^{-3} according to the 2024 pricing. In the case of irrigation in a 50,000 m^2 greenhouse in the province of Antalya, depending on the values of radiation, the annual water consumption will be 58,676.0 m^3 and the annual fee will be USD 715.1. However, in the province of Antalya, if rainwater is harvested in the greenhouse and 90% of the rainfall is collected, the irrigation fee that can be saved was calculated to be USD 577.7 if the irrigation is given to the greenhouse with pressurized irrigation. The annual water consumption in the province of Adana is 55,458.9 m^3 and the annual fee will be USD 675.9 However, suppose that rainwater is harvested in the greenhouse in Adana, and 90% of the rainfall is collected. In that case, the irrigation fee that can be saved was calculated to be USD 366.8 if irrigation is given to the greenhouse with pressurized irrigation.

In the case of irrigation in a 50,000 m^2 greenhouse in the province of Afyonkarahisar, depending on the values of radiation, the annual water consumption will be 73,955.5 m^3 and the annual fee will be USD 901.3. In the province of Afyonkarahisar, the irrigation fee that can be saved was calculated to be USD 247.6. In the case of irrigation in a 50,000 m^2 greenhouse in the province of Kırşehir, depending on the values of radiation, the annual water consumption will be 68,538.6 m^3 and the annual fee will be USD 835.3. Furthermore, in the greenhouse in the province of Kırşehir, the irrigation fee that could be saved was calculated as USD 210.2.

According to the results, 80.8% of the total fee can be saved by rainwater harvesting, since Antalya's rainfall is higher than in other provinces. In Adana, 54.3% of the total fee will be covered. In the province of Afyonkarahisar, which has a continental climate, 27.5% of the total fee can be saved by rainwater harvesting. Due to the low rainfall in the province of Kırşehir, the amount that can be saved will be 25.2%. Ertop et al. [13] determined that if rainwater harvesting is carried out in greenhouses in the province of Antalya, because of one year's rain harvest, producers can earn a total economic gain of USD 1,237,460.38 with gravity irrigation and USD 3,149,899.14 with pressurized irrigation. They reported that the profit from tomato cultivation may increase due to the gain from irrigation, which may lead to a positive trend towards rain harvesting in greenhouse enterprises.

3.3. Adoption of Rainwater Harvesting in Greenhouse Enterprises, Determination of Some Limitations and Institutional Support

The rainwater harvesting method, which is not widely used in Turkey, will effectively solve the problems encountered in arid and semi-arid regions [47]. Looking at the studies conducted by researchers on adopting rainwater harvesting, Carvajal et al. [48] reported that groundwater resources are intensively used to supply water to the increasing greenhouse agriculture in southeastern Spain. They reported that harvesting rainwater could be an excellent alternative to increase the availability of water resources and minimize the use of groundwater, but despite all these advantages, the use of rainwater by farmers in this area is limited. Similarly, in a study on using rainwater harvesting for irrigation purposes, Velasco-Muñoz et al. [49] found that this technique was used at a low level in greenhouses. However, it requires low levels of investment and has great potential for collecting rainwater. López-Felices et al. [50] reported that competent authorities should encourage rainwater harvesting systems in southeastern Spain to enable and popularize farmers' use of rainwater harvesting for agricultural irrigation. They also found that there should be a focus on increasing farmers' education, providing them with financial support, and increasing environmental awareness. Considering the studies carried out by researchers, it has been stated that rainwater harvesting is very important in reducing the pressure on underground and surface water resources and decreasing irrigation costs by saving water in enterprises. In addition, it was concluded that focus should be placed on disseminating information on rainwater harvesting to enterprises. Moreover, López-Felices et al. [50] stated that there are various approaches to increase farmers' awareness of these aspects, such as organizing educational programs such as workshops, seminars and training sessions; conducting publicity campaigns or arranging field demonstrations. Additionally, efforts can be made to raise public awareness about the benefits of RWH so that farmers can gain commercial benefits from using environmentally friendly techniques. Similarly, rainwater harvesting needs to be expanded in greenhouse enterprises in Turkey. Water consumption in high-tech greenhouses is very large, and this water is generally supplied by groundwater. The adoption of rainwater harvesting by greenhouse enterprises will also reduce the pressure on underground and surface water resources.

Electrical conductivity is a measure of water's salinity, one of the most important factors affecting the quality of irrigation water, and tolerance of conductivity varies depending on the type of crop [51,52]. Therefore, using water at high levels of conductivity is important to prevent yield losses. Irrigation with water with high electrical conductivity (EC) levels may affect the nutrient uptake capacity of plants [53]. On the other hand, if the conductivity of irrigation water is very low, it may not be sufficient to meet the nutrient needs of plants [51]. In this case, nutrients can be provided by the use of fertilizers [50]. Additionally, microbiological activities that will occur over time due to keeping water in ponds should be prevented. Water quality parameters are very important, since irrigation and fertilization in high-tech greenhouses depend on the pH and EC. Therefore, the quality parameters of rainwater harvested in enterprises must be determined. For this reason, it is important to purify rainwater using reverse osmosis, ultraviolet light and ozonation methods. Another critical problem is sediment in the water harvested from greenhouse surfaces. It is essential to prevent dirt from entering the pond because otherwise, it can clog the irrigation system and prevent even adequate crop irrigation [54]. In this case, filtering methods are important for reducing losses in efficiency.

Although there are regulations on rainwater collection, storage and discharge systems in Turkey, there are no regulations on the water harvested in greenhouses and its use. In addition, the large size of the storage pools to be established by greenhouse enterprises is one of the biggest obstacles for the enterprises. Businesses need to use an area equal to the greenhouse area or buy or rent this area if it does not belong to the business. This will also cause high initial investment costs for businesses. However, the construction of large-scale storage ponds through state support or local governments and their operation with appropriate regulations will facilitate the adoption of rainwater harvesting.

4. Conclusions

Harvesting rainwater and using it for plant irrigation in arid and semi-arid areas where water resources are insufficient is important for sustainability in greenhouse cultivation. In this study, the amount of irrigation in the hydroponic greenhouse was calculated according to the intensity of solar radiation. The amount of water consumed per unit of area in the greenhouses in the provinces of Antalya and Adana, where a Mediterranean climate is observed, was 1173.52 and 1109.2 L m^{-2} yr^{-1}, depending on the production period. In the provinces of Afyonkarahisar and Kırşehir, where continental climates are observed, water consumption was calculated to be 1479.11 and 1370.77 L m^{-2} yr^{-1}. Storage volumes were found to be 438.39 L m^{-2}, 122.71 L m^{-2}, 42.12 L m^{-2} and 43.65 L m^{-2} for the provinces of Antalya, Adana, Afyonkarahisar and Kırşehir, respectively. The proportion of plants' water consumption by met rainwater harvesting in the provinces was calculated to be 80.79%, 54.27%, 27.47% and 25.16% for the provinces of Antalya, Adana, Afyonkarahisar and Kırşehir, respectively. In addition, the amount of savings that could be achieved through rainwater harvesting was USD 901.3 for the province of Antalya, USD 835.3 for Adana, USD 247.6 for Afyonkarahisar and USD 210.2 for the province of Kırşehir. According to the study's results, although the need for irrigation water increases due to increasing solar radiation in regions with a Mediterranean climate, the rate of meeting plants' water requirements with rainwater harvesting will be higher than in regions with a continental climate. This will contribute to greenhouse enterprises in terms of saving water and reducing irrigation costs. However, in regions with a Mediterranean climate, high storage volumes will bring high business costs. But its construction with governmental support and operation with appropriate regulations will make it easier for businesses to adopt rainwater harvesting. Accordingly, the rainwater that can be collected, depending on the amount of precipitation in the provinces investigated in the study, will not only provide economic gain to greenhouse enterprises but will also contribute to reducing the negative effects of irregular precipitation regimes that occur due to climate change on underground and surface water resources. In addition, it was concluded that the focus should be placed on disseminating information on rainwater harvesting in greenhouse enterprises.

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

Funding: This research received no external funding.

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

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

References

1. Rolbiecki, R.; Yücel, A.; Kocięcka, J.; Atilgan, A.; Marković, M.; Liberacki, D. Analysis of SPI as a Drought Indicator during the Maize Growing Period in the Çukurova Region (Turkey). *Sustainability* **2022**, *14*, 3697. [CrossRef]
2. İnce Kaya, Ç.; Yazar, A. Saltmed model performance for quinoa irrigated with fresh and saline water in a mediterranean environment. *Irrig. Drain.* **2016**, *65*, 29–37. [CrossRef]
3. Kale Celik, S. Deficit irrigation under water stress and salinity conditions: Fao-aquacrop model. *Infrastruct. Ecol. Rural Areas* **2022**, *17*, 96–106.
4. Uçak, A.B.; Atılgan, A.; Korytowski, M.; Kocięcka, J.; Liberacki, D.; Stachowski, P.; Saltuk, B.; Rolbiecki, R. Derinkuyu dry bean irrigation planning in semi-arid climate by utilizing crop water stress index values. *J. Water Land Dev.* **2023**, *59*, 1–8. [CrossRef]
5. Yazar, A.; İnce Kaya, Ç.; Çolak, Y.B.; Tekin, S.; Alghory, A. Yield, dry matter and water productivity simulation for surface and subsurface drip-irrigated bell pepper using the SALTMED model. *J. Agric. Sci.* **2023**, *161*, 76–87. [CrossRef]
6. Greve, P.; Kahil, T.; Mochizuki, J.; Schinko, T.; Satoh, Y.; Burek, P.; Fischer, G.; Tramberend, S.; Burtscher, R.; Langan, S.; et al. Global assessment of water challenges under uncertainty in water scarcity projections. *Nat. Sustain.* **2018**, *1*, 486–494. [CrossRef]
7. Knox, J.W.; Kay, M.G.; Weatherhead, E.K. Water regulation, crop production, and agricultural water management—Understanding farmer perspectives on irrigation efficiency. *Agric. Water Manag.* **2012**, *108*, 3–8. [CrossRef]
8. Siebert, S.; Burke, J.; Faures, J.M.; Frenken, K.; Hoogeveen, J.; Döll, P.; Portmann, F.T. Groundwater use for irrigation—A global inventory. *Hydrol. Earth Syst. Sci.* **2010**, *14*, 1863–1880. [CrossRef]
9. Parker, D.B.; Brown, M.S. Water Consumption for Livestock and Poultry Production. 2023. Available online: https://www.researchgate.net/publication/269393738_Water_consumption_for_livestock_and_poultry_production (accessed on 10 October 2023).
10. Parker, D.B.; Perino, L.J.; Auvermann, B.W.; Sweeten, J.M. Water use and conservation at Texas high plains beef cattle feedyards. *Appl. Eng. Agric.* **2000**, *16*, 77–82. [CrossRef]
11. Bafdal, N.; Dwiratna, S.; Kendarto, D.R.; Suryadi, E. Rainwater harvesting as a technological innovation to supplying crop nutrition through fertigation. *Int. J. Adv. Sci. Eng. Inf. Technol.* **2017**, *7*, 1970–1975. [CrossRef]
12. Islam, S.; Lefsrud, M.; Adamowski, J.; Bissonnette, B.; Busgang, A. Design, construction, and operation of a demonstration rainwater harvesting system for greenhouse irrigation at McGill University, Canada. *HortTechnology* **2013**, *23*, 220–226. [CrossRef]
13. Ertop, H.; Kocięcka, J.; Atilgan, A.; Liberacki, D.; Niemiec, M.; Rolbiecki, R. The importance of rainwater harvesting and its usage possibilities: Antalya example (Turkey). *Water* **2023**, *15*, 2194. [CrossRef]
14. Lye, D.J. Rooftop runoff as a source of contamination: A review. *Sci. Total Environ.* **2009**, *407*, 5429–5434. [CrossRef] [PubMed]
15. Liang, X.; van Dijk, M.P. Optimal level of groundwater charge to promote rainwater usage for irrigation in rural Beijing. *Water* **2011**, *3*, 1077–1091. [CrossRef]
16. Eslamian, S.; Eslamian, F. *Handbook of Water Harvesting and Conservation: Case Studies and Application Examples*; Wiley: Hoboken, NJ, USA, 2021; Volume 2.
17. Boyacı, S.; Arslan, K. Kurak ve Yarı kurak iklim koşullarında sera çatısından sulama amaçlı yağmur suyu hasadı. *Alatarım* **2023**, *22*, 44–54.
18. Baytorun, A.N.; Zaimoğlu, Z.; Ünlü, M. Determination of harvesting and storage capacity of rain water in greenhouse establishments. *Turk. J. Agric. Food Sci. Technol.* **2019**, *7*, 22–29.
19. Olaifa, O.P.; Abegunrin, T.P.; Chukwudebe, E.P.; Zaccheaus, O.S.; Balogun, A.C.; Ande, S.A. Incorporating Rain Water Harvesting Into The Greenhouse Farming. *J. Inf. Eng. Appl.* **2015**, *5*, 84–88.
20. Örs, İ.; Safi, S.; Ünlükara, A.; Yürekli, K. Su Hasadı Teknikleri, Yapıları ve Etkileri. *Tarım Bilimleri Araştırma Dergisi* **2011**, *2*, 65–71.
21. Pari, L.; Cozzolino, L.; Bergonzoli, S. Rainwater: Harvesting and storage through a flexible storage system to enhance agricultural resilience. *Agriculture* **2023**, *13*, 2289. [CrossRef]
22. Londra, P.A.; Gkolfinopoulou, P.; Mponou, A.; Theocharis, A.T. Effect of Rainfall Regime on Rainwater Harvesting Tank Sizing for Greenhouse Irrigation Use. *Hydrology* **2022**, *9*, 122. [CrossRef]
23. Piemontese, L.; Castelli, G.; Fetzer, I.; Barron, J.; Liniger, H.; Harari, N.; Bresci, E.; Jaramillo, F. Estimating the Global Potential Of Water Harvesting From Successful Case Studies. *Glob. Environ. Change* **2020**, *63*, 1–13. [CrossRef]
24. Jewell, L.P. Increasing Adoption Of On-Farm Water Recycling Technology In Culturally And Linguistically Diverse Communities In A Periurban Context—Key Challenges And Lessons. *Acta Hortic.* **2016**, *1112*, 31–37. [CrossRef]
25. Boyacı, S.; Kartal, S. Rainwater Harvesting on Greenhouse Roof and Use In Irrigation. *Int. J. Res. Granthaalayah* **2019**, *7*, 93–100. [CrossRef]
26. Boyaci, S.; Kartal, S. Rainwater Harvesting In Greenhouses Establishments and Use As Irrigation Water. *Int. J. Sci. Technol. Res.* **2019**, *5*, 1–8.
27. Singh, K.G.; Sharda, R.; Singh, A. Harvesting Rainwater From Greenhouse Rooftop For Crop Production. *Agric. Res. J.* **2019**, *56*, 493–502. [CrossRef]
28. Kläring, H.-P. Strategies to control water and nutrient supplies to greenhouse crops. A review. *Agronomie* **2001**, *21*, 311–321. [CrossRef]
29. Lin, D.; Wambersie, L.; Wackernagel, M.; Hanscom, P. (Eds.) Global Footprint Network. In *Calculating Earth Overshoot Day 2020, Estimates Point to August 22nd*; Global Footprint Network: Oakland, CA, USA, 2020.

30. Sambo, P.; Nicoletto, C.; Giro, A.; Pii, Y.; Valentinuzzi, F.; Mimmo, T.; Lugli, P.; Orzes, G.; Mazzetto, F.; Astolfi, S.; et al. Hydroponic solutions for soilless production systems: ıssues and opportunities in a smart agriculture perspective. *Front. Plant Sci.* **2019**, *10*, 923. [CrossRef] [PubMed]
31. Gruda, N.S. Advances in Soilless Culture and Growing Media in Today's Horticulture—An Editorial. *Agronomy* **2022**, *12*, 2773. [CrossRef]
32. Bridgewood, L. *Hydroponics: Soilless Gardening Explained*; The Crowood Press Limited: Marlborough, UK, 2003.
33. Richa, A.; Touil, S.; Fizir, M.; Martinez, V. Recent advances and perspectives in the treatment of hydroponic wastewater: A review. *Rev. Environ. Sci. Bio/Technol.* **2020**, *19*, 945–966. [CrossRef]
34. Swain, A.; Chatterjee, S.; Vishwanath, M. Hydroponics in vegetable crops: A review. *Pharma Innov. J.* **2021**, *10*, 629–634.
35. Nisha, S.; Somen, A.; Kaushal, K.; Singh, N.; Chaurasia, O.P. Hydroponics as an advanced technique for vegetable production: An overview. *J. Soil Water Conserv.* **2019**, *17*, 364–371. [CrossRef]
36. Rosa, L.; Gonzabay, J. Economic analysis of hydroponic lettuce under floating root system in semi-arid climate. *Granja Rev. Cienc. Vida* **2020**, *31*, 121–133. [CrossRef]
37. Baytorun, A.N.; Zaimoğlu, Z.B.; Erkurt, F.E.; Balci, B.; Yeşiltaş, H.K. Calculation of rainwater harvest in greenhouses for semi-arid and continental climate zones. *Environ. Res. Technol.* **2022**, *5*, 188–196. [CrossRef]
38. Ntinas, G.K.; Neumair, M.; Tsadilas, C.D.; Meyer, J. Carbon footprint and cumulative energy demand of greenhouse and open-field tomato cultivation systems under Southern and Central European climatic conditions. *J. Clean. Prod.* **2017**, *142*, 3617–3626. [CrossRef]
39. Gartmann, F.; Hügly, J.; Krähenbühl, N.; Brinkmann, N.; Schmautz, Z.; Smits, T.H.M.; Junge, R. Bioponics-An organic closed-loop soilless cultivation system: Yields and characteristics compared to hydroponics and soil cultivation. *Agronomy* **2023**, *13*, 1436. [CrossRef]
40. Massa, D.; Incrocci, L.; Maggini, R.; Carmassi, G.; Campiotti, C.A.; Pardossi, A. Strategies to decrease water drainage and nitrate emission from soilless cultures of greenhouse tomato. *Agric. Water Manag.* **2010**, *97*, 971–980. [CrossRef]
41. TÜİK, 2022. Bölgesel Istatistikler. Available online: https://biruni.tuik.gov.tr/bolgeselistatistik/ (accessed on 2 April 2023).
42. Meteoroloji Genel Müdürlüğü. Climate Kırsehir (Turkey). Available online: https://www.mgm.gov.tr/veridegerlendirme/il-veilceler-istatistik.aspx?m=KIRSEHIR (accessed on 10 February 2024).
43. von Zabeltitz, C. *Integrated Greenhouse Systems for Mild Climates*; Springer: Berlin/Heidelberg, Germany, 2011; 360p.
44. Londra, P.A.; Kotsatos, I.E.; Theotokatos, N.; Theocharis, A.T.; Dercas, N. Reliability Analysis Of Rainwater Harvesting Tanks For Irrigation Use In Greenhouse Agriculture. *Hydrology* **2021**, *8*, 132. [CrossRef]
45. Liberacki, D.; Kocięcka, J.; Stachowski, P.; Rolbiecki, R.; Rolbiecki, S.; Sadan, H.A.; Figas, A.; Jagosz, B.; Wichrowska, D.; Ptach, W.; et al. Water Needs of Willow (*Salix* L.) in Western Poland. *Energies* **2022**, *15*, 484. [CrossRef]
46. Rolbiecki, S.; Rolbiecki, R.; Sadan, H.A.; Jagosz, B.; Kasperska-Wołowicz, W.; Kanecka-Geszke, E.; Pal-Fam, F.; Atilgan, A.; Krakowiak-Bal, A.; Kuśmierek-Tomaszewska, R.; et al. Sustainable Water Management of Drip-Irrigated Asparagus under Conditions of Central Poland: Evapotranspiration, Water Needs and Rainfall Deficits. *Sustainability* **2024**, *16*, 966. [CrossRef]
47. Yeniçeri, M. Harvesting of Rain Water and Active Use In Agricultural Irrigation. *J. Disaster Risk* **2018**, *1*, 126–136.
48. Carvajal, F.; Agüera, F.; Sánchez-Hermosilla, J. Water Balance in Artificial On-farm Agricultural Water Reservoirs For The Irrigation Of Intensive Greenhouse Crop. *Agric. Water Manag.* **2014**, *131*, 146–155. [CrossRef]
49. Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; Batlles-Delafuente, A.; Fidelibus, M.D. Rainwater Harvesting for Agricultural Irrigation: An Analysis of Global Research. *Water* **2019**, *11*, 1320. [CrossRef]
50. López-Felices, B.; Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; Román-Sánchez, I.M. Factors Influencing The Use Of Rainwater For Agricultural Irrigation: The Case Of Greenhouse Agriculture In Southeast Spain. *Water Infrastruct. Ecosyst. Soc.* **2023**, *72*, 185–201. [CrossRef]
51. Zaman, M.; Shahid, S.A.; Heng, L. Irrigation Water Quality. In *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*; Springer: Cham, Switzerland, 2018; pp. 113–131. [CrossRef]
52. Ourimbah, V.B.; Brunton, V.; Ourimbah, V.B. Irrigation Water Quality. Department of Primary Industries. 2011; pp. 1–3. Available online: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/433643/Irrigation-water-quality.pdf (accessed on 30 June 2024).
53. Rameshwaran, P.; Tepe, A.; Yazar, A.; Ragab, R. Effects of drip-irrigation regimes with saline water on pepper productivity and soil salinity under greenhouse conditions. *Sci. Hortic.* **2016**, *199*, 114–123. [CrossRef]
54. Bonachela, S.; Juan, M.; Casas, J.J.; Fuentes-Rodríguez, F.; Gallego, I.; Elorrieta, M.A. Pond management and water quality for drip irrigation in Mediterranean intensive horticultural systems. *Irrig. Sci.* **2013**, *31*, 769–780. [CrossRef]