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The Effect of different Irrigation Systems on Water use Efficiency and Yield using Soilless Cultivation

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ABSTRACT

Climate change and irrigation water scarcity called attention to investigate the cultivation technology that saves water and maximizes plant production. The objective of this study is to investigate the effect of using a soilless closed irrigation system (SC) on saving irrigation water and maximizing crop production as compared to a soilless open (SO) and conventional (C) irrigation system. The randomized complete block experimental design was used to overcome the planting variations. The experiment was applied to cucumber plants. The irrigation systems were provided with valves and meters that enable the measurement of irrigation amounts and the drainage water for both closed and open systems. The experiment design was supplied by the equipment needed to circulate the drainage water for irrigation in the SC. The measurements in the experiment included climate measurements, irrigation water used, water use efficiency, cucumber yield per harvest, and the total cucumber yield for each treatment. The results showed that the net water used for irrigation significantly decreased in the SC treatment due to drained water circulation as compared to the SO treatment without water circulation and the C treatment. The C treatment showed the highest irrigation water requirements. The crop yield related to the cucumber seedlings and total yield showed the highest yield for the SC treatment followed by the SO treatment and the lowest yield was for the conventional systems. It was concluded that the highest water use efficiency and crop production were recorded for the SC treatment compared to SO and C treatments. The study recommended an increase in farmers' awareness of SC irrigation systems and investment the technology in this area.

Keywords: Soilless Closed system, Soilless Open system, Conventional system, Water use efficiency, Cucumber crop yield

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INTRODUCTION

Climate change affected the trends of rainfall and irrigation water availability in different global sites. As a response to climate change, efforts started to find cultivation technology that conserves water and stands the high temperatures increase. Gautam et al. (2021) and Banerjee et al. (2021) reported that the new irrigation systems included the hydroponic and aeroponic systems fitted the increase of production and minimizing the cultivation required area, side by side with reducing the plant irrigation requirements, minimizing the need for toxic chemicals and improve the ecological footprint. Banerjee et al. (2021) reported that soilless systems (SS) will help optimize the natural sources mainly soil and water which will reduce the impact on the environment. Moreover, Birlanga et al. (2022) called the attention that the SS provides a new opportunity for cultivation in urban areas which will help increase the food production in areas close to the consumers. Fussy and Papenbrock (2022) reported that the SS will contribute to enriching food and nutrition security through the mitigation of the climate change effects.

The SS started to gain higher popularity as a sustainable alternative to traditional soil agricultural systems. Yegül (2023) reported that since the SS will maximize production and increase profits by minimizing the pressure on natural resources is considered a feasible

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alternative to traditional agriculture. Mourouzidou et al. (2023) and Vagisha et al. (2023) found that the SS facilitates the application of nutrient-rich solutions which will be absorbed by the roots directly which will minimize the use of fertilizers and maximize the production process. The reuse of drained water from the SS for irrigation will maximize the benefit of fertilizers through the growing season.

The SS were found to suit a wide variety of crops forming another factor to encourage its use over traditional farming (Vagisha et al. 2023). The SS allows high farming control using technology such as sensors which facilitate the following of crop conditions that minimize maintenance costs and improve crop management (Sharma et al., 2022). The SS is considered the sustainable alternative to increase food security through increasing crop production, facilitating disease control, and overcoming land unavailability for agricultural purposes. Jordan, just like many countries suffers from water scarcity, soilless farming would affect agricultural activities in three directions, it helps save water, increase productivity, and produce more feasible production. This paper will investigate the effect of soilless systems on water, production, and economic direction.

Some areas, like Jordan, are suffering from water scarcity and non-arable lands due to desertification and climate change. Moreover, the scarcity of water increased after the deepening of climate change due to decreased annual rainfall rates, delays, and uncertainty of rainfall. The soilless agricultural systems are expected to save the use of water for irrigation. The agricultural business is considering the use of alternative irrigation systems at the same time it insists on the quantity and quality of production which is considered the core of agribusiness. The objective of this study is to investigate the differences in crop water use efficiency (WUE) and production of soilless closed (SC) and soilless open (SO) systems as compared to conventional (C) systems.

The SS applied techniques formed a dramatic transition in agricultural practice. Unlike traditional agriculture, Yegül (2023) reported that the SS provides a solution for clean water resources, pests, climate change, and an effective solution for soilborne diseases. Joshi et al. (2022) reported another benefit of the SS represented in the possibility of cultivation without soil which will be suitable for practicing in urban areas and areas difficult to farm. Vanacore and Cirillo (2023) reported that the SS has higher productivity and irrigation water savings than conventional agriculture. Ghorbel et al. (2021) explained the possibility of the use of organic fertilizers in the SS which decreased the danger of using chemical fertilizers which are environmentally friendly and sustain food production. Sivakumar et al. (2022) summarized the conditions that maximize the benefits of SS which include the limited agricultural lands, water scarcity, pollution, and food security suffering areas. These benefits provide solutions for the areas suffering from arable lands and saline soils.

Closed irrigation systems (CIS) provide many advantages over conventional ones. Kovalenko et al. (2022) and Karpenko and Rudakova (2022) discussed different advantages related to the CIS including the efficiency of energy and water use, reducing specific costs, increasing environmental reliability, and improving the water flow uniformity through the system. The CIS will help preserve the pressure in the system and provide remote control. The CIS systems can be automated using different sensors which provide more control and minimize the labor needed to maintain the system. The CIS was found to affect the irrigation water needs in different ways.

Kovalenko et al. (2022) described the benefits of using CIS when implementing a complex technology, resource-saving measures, and optimal technical management represented in saving irrigation water consumption by 2.2 to 30.7%, while the electricity consumption will be reduced by 12.9 to 38.2%. Karpenko and Rudakova (2022) focused on the additional water control and use efficiency if sensors are used for control and data collection from the system. Klein et al. (2018) found that the use of closed-loop irrigation will improve the used efficiency by 16% and increase the yield by 26%. Expósito and Berbel (2017) found that the effectiveness of the CIS is highly influenced by the technology. The technological limitations will minimize the control and decrease the efficiency of the system. Makone et al. (2021) reported that the CIS can increase the effectiveness of irrigation and nutrient absorption if it works through a combination of water spray and nutrient injection systems.

The effect of CIS on utilizing the fertilizers increased the crop yield. De la Rosa-Rodríguez et al. (2020) found that the CIS for tomato production reduced the fertilizer need by 10.31g/kg compared to the open systems. Younis and Younis (2017) have shown that the use of automatic adjustment tools in the CIS will determine the proper crop need for water and energy consumption. Automated systems were found to improve the fertilizers' efficiency use and increase production. Kovalenko et al. (2022) found that the improvement of the water efficiency and fertilizer use in CIS reflected directly on the costs. They found that the general cost decreased by 1.32 to 1.47%, while the environmental reliability increased by 5.6 to 16.7%. On the other hand, the profitability index also, increased from 1.07 to 1.75-2.57% and the discounted payback period decreased from 18.0 to 8-5 years.

Sharma et al. (2022) reported that cucumber production was affected by different factors related to fertigation strategies, irrigation, and nutrient management. The experiments showed that cucumber yield increased as a response to the use of a mixture of organic and inorganic fertilizers with an increase of 50.22% over the control. The optimized fertigation strategies using the nutrient solutions enabled the production of 96.88 to 104.89ton/ha (Khessro et al., 2022). The balanced management of water side by side with balanced nutrients affected the cucumber production with a yield reaching 88.41ton/ha (Li et al., 2023).

MATERIALS & METHODS

Experiment Location

The experiment was conducted in the East Irbid area in the north part of Jordan (32.581236°N, 35.903026°E) with 560m elevation. The experiment was conducted in the period August 4th to October 5th, 2023.

Experiment Treatments

Three treatments of the SC, SO, and C cultivation systems were used, with three replications. The experiment consists of three greenhouses, each including the three treatments.

Experiment Design

A randomized complete block design (RCBD) was used to execute this experiment. The RCBD design was used to treat the variances among treatments in the different greenhouses.

Irrigation Treatments and Design

Fig. 1 shows the experiment design and layout. The main reservoir was used as a source of irrigation water for the three irrigation systems. The reservoir was connected to a filling pump and water meter that measures the total amount of water pumped from the main sources. Three tanks were used for each irrigation system (SC, SO, and C). The outlet of each tank was provided by an irrigation pump, solenoid valve, and water meters to measure the amount of irrigation water. Each tank distributed water for the same treatment in the three greenhouses. The amount of water recorded for each system represents the amount used for irrigation for the same treatment in the three greenhouses. From the other side of the greenhouse, drain water meters were constructed for the SC and SO treatments in each greenhouse. For the SC treatment, accumulation tanks for the drained water were constructed with a submersible pump to reuse the drained water for irrigation.

Site Preparations

The greenhouses used in the experiment were tested for their compatibility and capability to meet the experiment requirements. Each greenhouse has three treatments. The conventional agricultural methods were prepared and were provided with driplines as an irrigation system. The SC and SO systems (Dutch Buckets) were provided by two layers of volcanic tuff. The first layer consists of course tuff and the upper layer consists of fine tuff where the crop roots were located and provided by the essential growing needs. In the SC treatment, the drained irrigation water was collected in the water tank and pumped once more to the tank that feeds the SC treatment to be used in irrigation once more.

Crop and Fertilization

Cucumber was used for planting. The number of cucumber seedlings used per treatment reached 180 seedlings. In the first stages of the experiment, any lost seedling was replaced by another to ensure that the number of seedlings was equal among the three treatments. Three fertilizer solutions were used in SC and SO treatments. Solution A consists of 17kg of calcium nitrite in addition to 300 grams of Fe EDDHA 6%; solution B consists of 17kg of NPK-12-12-36, 7kg of NPK-10-3-43, and 8kg of magnesium sulfate in addition to 400gm of microelements; and solution C consists of phosphoric acid as a pH buffer. Organic fertilizer was only applied for the C treatment with the amounts popular in the experiment area.

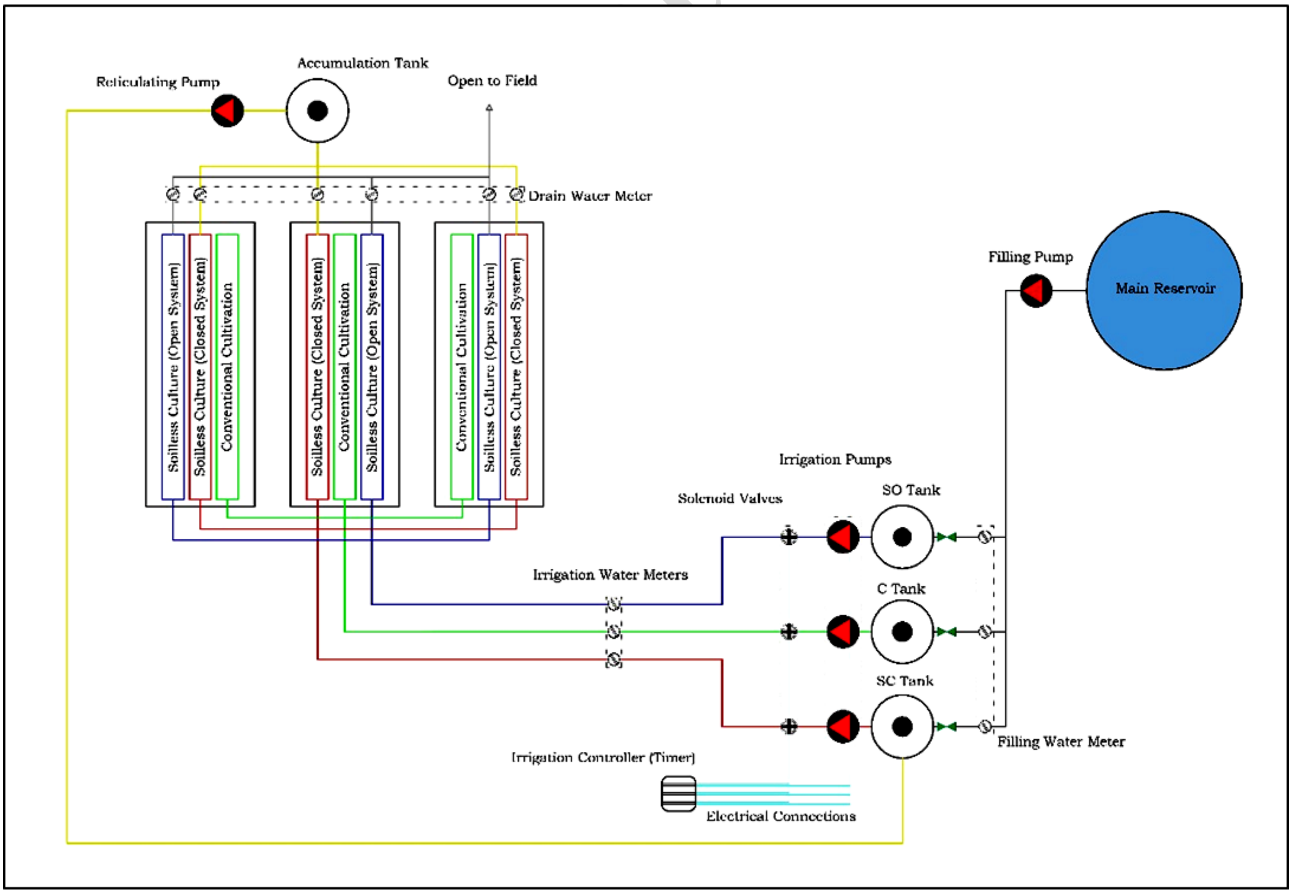

Fig. 1: Experiment design and layout.

General Measurements

Air temperature (°C) and the humidity (%) inside the greenhouses were recorded to determine the amount of water needed for each of the three treatments. Irrigation water pH and electrical conductivity (EC) (dS/m) were measured regularly to ensure that the water was within the required characteristics. These measurements were taken day after day or every two days maximum to ensure the healthy conditions of the plants.

Irrigation Measurements

Irrigation water input was measured and recorded for the three treatments daily, while drained water was measured and recorded only for the SC and SO treatments daily. Water use efficiency was calculated based on the production per unit of irrigation water.

Crop Measurements

The plant measurements included the yield of each treatment per harvest and the total yield over the time of the experiment. The total number of yield harvestings reached 48 times through the period of the experiment.

Statistical Analysis

The RCBD analysis of variance (RCBD ANOVA) was used to measure the variation among the treatments. The least significant differences (LSD) were used to measure the mean separation of the treatments.

RESULTS

Greenhouse Conditions and Irrigation Water Demand

The greenhouse temperature and humidity were recorded every two days according to the weather conditions. The results showed that the mean temperature recorded was 33.8°C with a minimum of 25°C and a maximum of 44°C. Fig. 2A shows that the highest increase in the greenhouse temperature occurred in mid-August at the first stages of the experiment period. This led to the increase of water irrigation to meet the cucumber requirements. A slight increase in temperature over the mean was recorded mid of September which required slight changes in the irrigation requirements. In the rest period of the experiment, the greenhouse temperatures were close to or below the recorded mean temperature. The average humidity recorded in the greenhouse was 60% with a minimum value of 55% and a maximum value of 68%. Fig. 2B shows humidity fluctuation around its average in the greenhouses. These fluctuations were considered in the irrigation treatments.

Concerning the chemical properties of the irrigation water, the results showed that the average irrigation water pH was 6 with minimum and maximum values of 5.7 and 6.4, respectively. The recorded pH values were close to the average (Fig. 2C). The average EC recorded was 2.24dS/m with a minimum and maximum of 1.5 and 2.8dS/m, respectively. Fig. 2D shows that the values of EC were below the average at the beginning of the season, while it was more than the average in the second half of the experiment.

Irrigation water requirements were not constant throughout the experiment and were affected by the external and the inside temperature of the greenhouse. Fig. 2 shows that the temperature inside the greenhouse was above the average over the time of the experiment in some stages. The highest increase in temperature was at the start of the plant growth which required an increase of the irrigation water amounts to meet the increase of temperatures. Fig. 3 shows that the highest increase in irrigation amounts was for the C treatment, while the marginal increase was for the SO, and the least was recorded for the SC treatment.

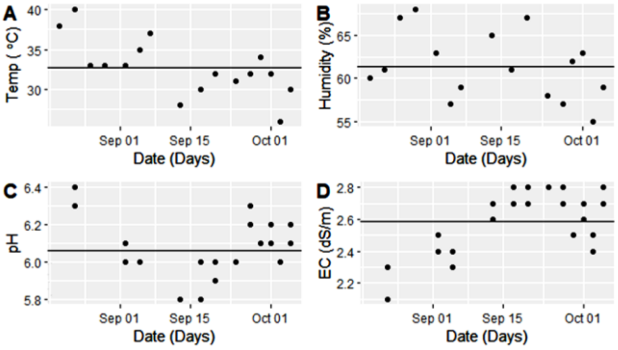

Fig. 2: A) Temperature (^{0}C), B) humidity (%) of the greenhouse, C) pH, and D) EC (dS/m) of irrigation water.

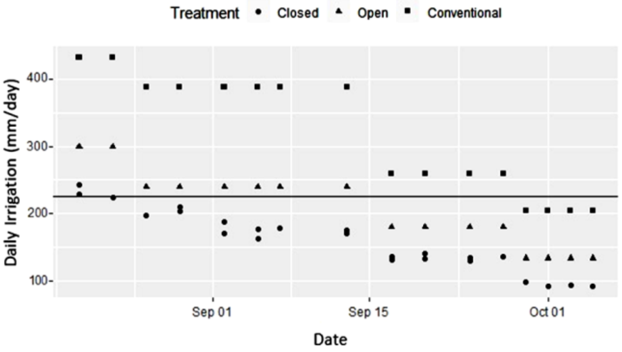

Fig. 3: The effect of temperature on irrigation water needs.

Irrigation Water use

The cucumber irrigation water needs under the SC, SO, and C treatments changed through the growing season. The SC, SO, and C treatments used 379, 497, and 757m^3/ha, respectively, to reach the production stage (Table 1). The increase of irrigation water needs continued for the three treatments with different variations. The irrigation water used to reach the different harvests was less for SC compared to the SO and C treatments. Irrigation water needs increased from 379, 497, and 757m^3/ha, to reach the first harvest, to 1276, 1690, and 2591m^3/ha, to reach the last harvest, for SC, SO, and C, respectively (Table 1).

Only 50.1% and 65.6% of irrigation water needed for C treatment were needed for SC and SO treatments, respectively, to reach the first harvest (Fig. 4). On the other hand, about 76.3% of the water used in SO was used in the SC system. The irrigation water needed under SC

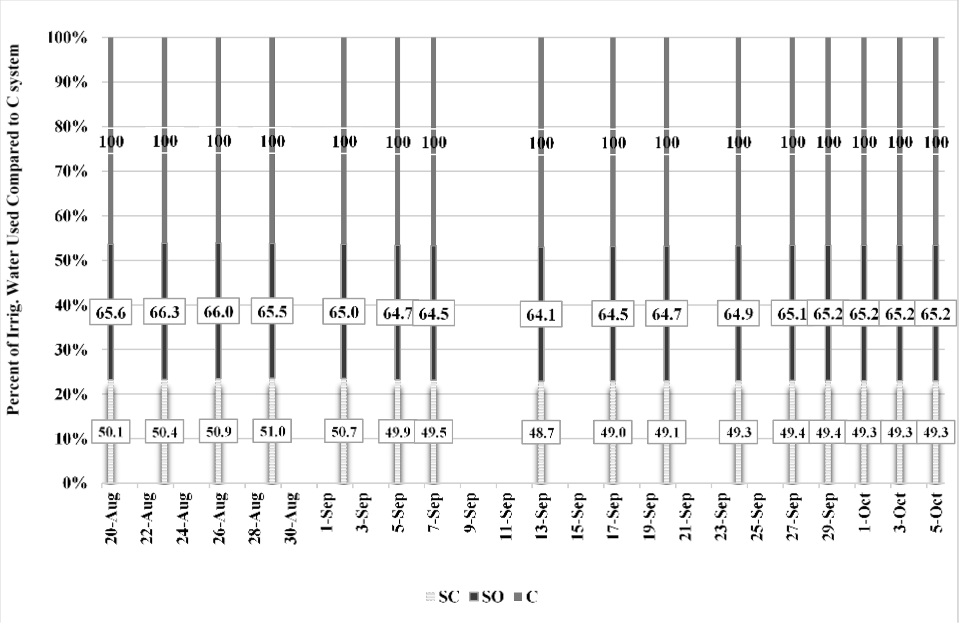

Fig. 4: Percent of irrigation water used for SC and SO compared with the C treatment through the growing season.

Table 1: The cumulative amounts of irrigation water needed to reach each harvest for the soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments

Harvesting Event	Cumulative Irrigation Water (m^3/ha)		
	SC	SO	C
20-August	379	497	757
23-August	460	605	912
26-August	538	698	1058
29-August	611	785	1198
2-September	701	900	1384
5- September	760	986	1524
7- September	801	1044	1617
13- September	925	1217	1897
17- September	991	1303	2022
20- September	1039	1368	2115
24- September	1103	1454	2240
27- September	1152	1519	2333
29- September	1181	1557	2388
1- October	1230	1626	2493
3- October	1253	1658	2542
5- October	1276	1690	2591

Table 2: The RCBD ANOVA analysis for the irrigation water needed under soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments

Irrigation treatment	Mean (m^3/ha)**	P**
SC	1276c	***
SO	1690b	
C	2591a	

Means with different letters in a column are significantly (**) different at P<0.05 and highly significant (***) at P<0.001.

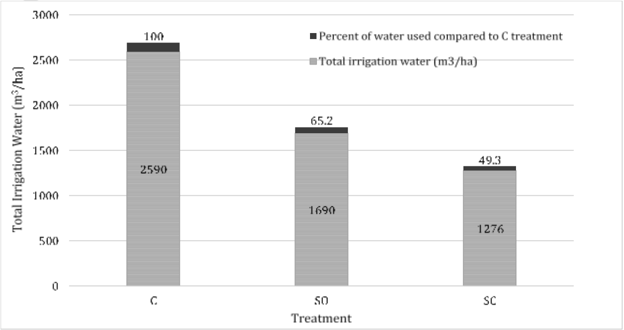

Fig. 5: The total amounts of irrigation water needed under soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments and the percentage of irrigation water used compared to C treatment.

treatment was around half that needed for C treatment, to reach each harvest all through the season. For SO treatment, the variations in the amounts of irrigation water needed to reach each harvest continued to be almost similar to the percent of the total amount of irrigation water needed under the C treatment (Fig. 4).

The RCBD analysis of variance showed significant variation among the irrigation treatments SC, SO, and C (P<0.001, Table 2). The results showed that the mean amounts of total irrigation per treatment for SC was 1276m^3/ha, followed by 1690m^3/ha for SO, and the highest (2591m^3/ha) was recorded for the C treatment. Fig. 5 shows the total amounts of irrigation water needed under different treatments and the percentage of irrigation water needed under SC and SO compared to C treatment. The results showed that the lowest amounts of irrigation water were needed under the SC treatment with a percent reaching 49.3% of the total irrigation water needed under the C treatment. On the other hand, the second amount of irrigation water was recorded for the SO treatment (1690m^3/ha) with a percent of 65.2% of the irrigation water amounts needed under C treatment.

Fig. 6 shows that the distribution of the daily irrigation water used in SC treatment was around the median values which explains that the irrigation water in the SC treatment had close trends over the time of the experiment which was presented in almost symmetrical around the median, while in the SO and C systems the median was in the third quarter which reflects the high amounts of irrigation water used under these two treatments compared to SC system.

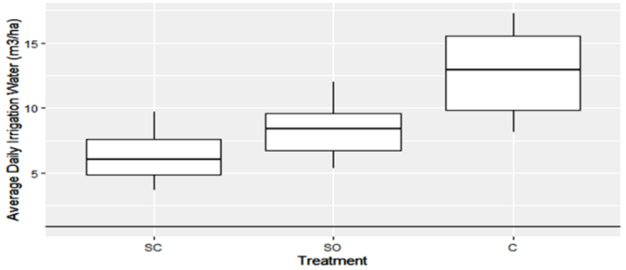

Fig. 6: The variation of daily irrigation water used for SC, SO, and C treatment over the growing season.

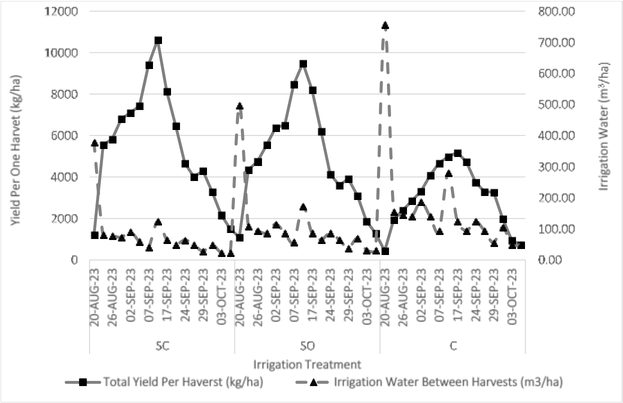

Fig. 7: The amount of irrigation water used among the different harvesting times soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments.

Production Characteristics

Despite that the SC irrigation systems are aimed at saving water and widening the agricultural activities in urban and areas of nonarable lands, production is still forming the core of agricultural activities. The SC irrigation system was found to meet both, the saving of irrigation water and maximizing the production. Fig. 7 shows that the SC recorded the lower amounts of needed irrigation water accompanied by the highest yield compared to the SO and C irrigation systems. The cucumber production for each harvest event started under the SC system with higher quantities (1221kg/ha) compared to SO (1092kg/ha) and C (432kg/ha). Also, the peak production through the growing season (September 13) was the highest recorded for the SC system (10608kg/ha) compared to (9493.1kg/ha) for SO and (4989.6kg/ha) for C treatment. At the end of the growing season, the production under the SC system dropped to (1497.6kg/ha) compared to the SO (1293.6kg/ha) and (723.6 kg/ha) under C treatment. On the other hand, the lowest amount of water needed between cucumber harvests was the lowest for SC treatment compared to SO and C treatments (Fig. 7).

The RCBD ANOVA showed highly significant differences in the means of the cucumber yield among the three treatments (P<0.001, Table 3). Fig. 8 shows that the highest cucumber total yield was recorded under the SC system (88485kg/ha), forming 1.82 times the C treatment production, and the cucumber yield under SO was 78907kg/ha, forming 1.63 times the cucumber yield under C treatment (48546kg/ha).

Table 3: The RCBD ANOVA analysis for cumber seasonal yield under soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments

Irrigation treatment	Mean (kg/ha) *	P**
SC	88485c	***
SO	78907b	
C	48546a	

Means with different letters in a column are significantly (*) different at P<0.05 and highly significant (***) at P<0.001.

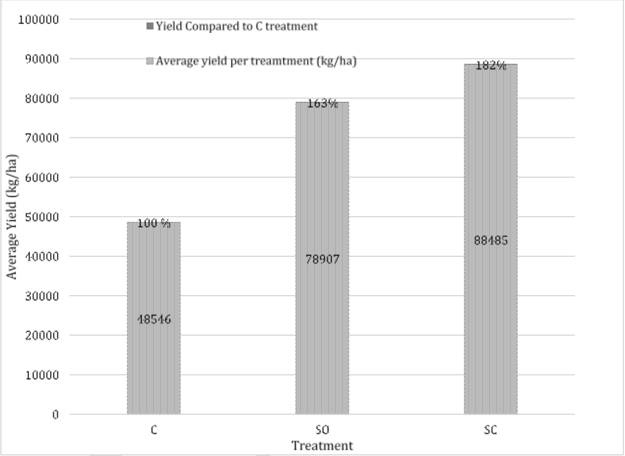

Fig. 8: Yield treatment comparison among soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments.

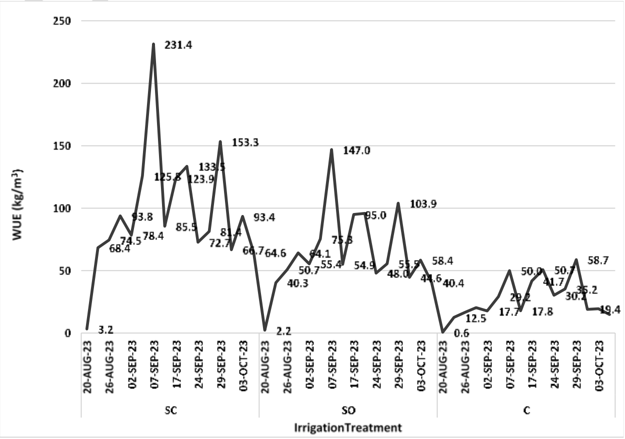

Fig. 9: Water use efficiency (kg/m3) for each harvest through the growing season for soilless closed (SC), soilless opened (SO) and Conventional (C) irrigation treatments.

Fig. 9 shows the water use efficiency (WUE, kg/m^3) for SC, SO, and C irrigation treatments. The highest WUE was recorded on September 13th for the SC irrigation treatment (231kg/m^3), the second highest WUE was recorded, also, for the SC treatment on September 29th (153kg/m^3). The highest WUE was 147kg/m^3 for SO and 59kg/m^3 for C treatment. The highest WUE values, in general, were recorded for the SC irrigation treatment, followed by the SO treatment, and the least was recorded for the C irrigation treatment. The overall season WUE were 69.3Kg/m^3, 46.7Kg/m^3, and 18.7Kg/m^3 for SC, SO, and C treatments, respectively.

DISCUSSION

The results showed that greenhouses provide suitable growing conditions for soilless closed irrigation to grow cucumber plants. Sibiya and Sumbwanyambe (2020) showed that the optimal range of pH is 5.45 to 6.8. The pH recorded values for the irrigation water were within this range reflecting the irrigation water pH suitability. The irrigation water salinity recorded was within the optimal level for cucumber growth. Rahil et al. (2022) found that irrigation water salinity (ECw) less than 2.2dS/m will increase WUE with high management of irrigation water. Oliveira et al. (2022) found that ECw value of 3dS/m is tolerable for the production of some crops such as cucumber.

The irrigation water requirements varied during the growing season due to the changes in greenhouses' temperature and humidity. The water requirements increased from 0.4m^3/day at 26°C to 1.08m^3/day at 44°C with an increase of 63% for the C treatment compared to SC and SO treatments which increased from 0.4m^3/day at 25°C to 0.9m^3/day at 44°C with an increase of 56%. Awwad et al. (2016) found that increasing the temperature by 1°C led to a 3.28% increase in irrigation water.

The results showed that the mean daily irrigation water needed was the highest for the C treatment compared with SC and SO treatments. The cumulative daily irrigation water needed for C treatment to reach the production stage was two times the irrigation amount needed for the SC treatment. The higher irrigation water needed resulted from the deep percolation and the evaporation besides the transpiration of the cucumber plants. This justifies the low WUE recorded under the C treatment. Expósito and Berbel (2017) have shown that using a closed-loop irrigation system increased water use efficiency and crop yields.

The pattern of irrigation water demand was not constant over the growing season. By the end of the growing season, the irrigation water used for the SC and SO treatments formed 49.3% and 65.2% of the amount used under the C treatment, respectively.

The lowest variation in irrigation water needed was recorded under the SC treatment due to the absence of deep percolation and evaporation, and the effectiveness of using water for plant growth compared to the variations recorded under the SO and C treatments. The median line of the SC irrigation system was approximately less than the average irrigation water through the growing season which justifies the symmetric distribution of irrigation water needs over the growing season compared to the SO and C treatments. Kolhe et al. (2020) reported that the implementation of closed conduit irrigation water distribution systems can improve overall water use efficiency to 70-80% compared to conventional canal distribution networks with water use efficiency of 25-40%. Also, Kolhe et al. (2020) indicated that under a closed irrigation system, the control process of water use, and circulation is very high compared to open irrigation systems. The water balance in a closed greenhouse shows that roughly 85% of the water used for irrigation is recaptured, resulting in increased water use efficiency. The implementation of a complex of measures in closed irrigation networks has been found to reduce the consumption of irrigation water and electricity while increasing overall efficiency and profitability (Kovalenko et al., 2022).

Water use efficiency (kg/m^3) was the highest for the SC system compared to SO and C systems. The WUE started with 3.2kg/m^3 for SC at the beginning of the growing season compared to 2.2 kg/m^3 for the SO treatment. At the peak crop production, the WUE was 231kg/m^3 for SC treatment compared to lower values recorded for the SO system (147kg/m^3) and (59kg/m^3) for the C system. Results revealed that seasonal WUE under SC treatment was 1.48 and 3.7 times that under SO and C treatments, respectively, and WUE under SO treatment was 2.5 times that under C treatment. This could be attributed to the low amounts of irrigation water lost under the SC system compared to the other two systems.

The total yield under the SC and SO treatments was 182% and 163% higher compared to the C treatment. This is contributed to the higher water use efficiency under the SC followed by the SO and the higher utilization of the fertilizers through the circulation system. Gnoatto et al. (2018) and Barreto et al. (2015) have shown that closed irrigation systems have been found to have a positive effect on seedling growth. These systems, such as sub-irrigation and drip irrigation, provide higher water application uniformity, resulting in improved growth dynamics and water productivity (Nabayi et al., 2022). Abdelmaged et al. (2021) reported that compared to manual overhead irrigation systems, closed irrigation systems have shown higher plant growth parameters, including shoot height, leaf area, and root length. They also promote better water use efficiency, with lower water loss and higher water retention in the substrate.

The cucumber crop behavior related to the production varied widely among the three treatments. The results showed that the highest cumulative production of cucumber while a light increase in irrigation water demand was recorded under the SC treatment. On the other hand, the cumulative increase in production under the SO treatment was accompanied by a significant increase in the irrigation water. Under the SO treatment, the increase of net irrigation water was continuous without consistent trends with the increase in cumulative production. In a study on tomato and maize cultivation, it was found that farmers using closed-piped networks and open-canal networks made mistakes and were unconscious in their irrigation practices, resulting in excessive or insufficient water application (Aslan and Tekiner, 2017). Another study on potato production showed that converting from conventional ridged-row planting systems to wide-bed planting systems increased total yield and irrigation water use efficiency (Klein et al., 2018). Additionally, a study on irrigated cowpea found that reduced and conventional tillage systems resulted in higher yield and water use efficiency compared to zero and manual tillage systems. Therefore, the choice of irrigation system can have a significant impact on total yield, but the specific effects may vary depending on the crop and other factors.

Conclusion and Recommendations

This experiment was conducted in greenhouses which is a dominant agricultural system in Jordan and many agricultural areas in other countries. Greenhouses provide a good system to control the different growth conditions of the plants. The objective of this experiment was to investigate the effectiveness of soilless-closed, soilless-open, and conventional systems, as well as to investigate the effect of these systems on cucumber yield and water use efficiency. The results showed that the amount of irrigation water decreased dramatically under the usage of the SC system, followed by the SO system compared to the C system. The circulation and reuse of drainage water were very efficient in saving irrigation water and fertilizers. On the other hand, the SC system contributed to the increase in the production of cucumber due to the benefits of fertilizer circulation with the drained irrigation water. The results showed that the cucumber seedling production was the highest under the SC system compared to the other two systems. The study recommended the increase of farmers' awareness of the closed irrigation system to fight water irrigation scarcity and investing in technology to provide an efficient closed irrigation system with reasonable costs.

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Conflict of interest

The authors declare that this work does not have a conflict of interest.

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Data Availability Statements

The data of this research is available to the authors for any clarifications.

Author's Contribution

This work was planned and executed by both authors. Khaled Radi Al-Masaied analyzed and wrote the paper, and Ahmad Abu-Awwad revised the analysis and the required scientific correction for the manuscript and approved the work.

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