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Research article

Economic efficient use of soilless techniques to maximize benefits for farmers

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Abstract: The main challenge of the agricultural sector is the increasing pressure on natural resources, mainly water and arable land. Consequently, an urgent imperative arises to explore technological advancements that can boost food production in alignment with the growing demands. The Soilless Production System (SPS) emerges as a proficient approach for managing irrigation water, thereby making a significant contribution to food security. This research focuses on the efficient use of SPS and identifies the best economic use of the soilless techniques for different crops within an area characterized by limited land and water availability. The database for the study was generated through a farm survey to investigate the benefits of adopting SPSs as a sustainable agricultural practice. A linear programming approach was applied to develop an optimization model for resource allocation and crop mix selection, considering the development opportunities through the SPSs. Different scenarios were applied in the model. The results proved that adopting SPSs is a sustainable irrigation practice, since the technique promotes water use efficiency, generates profitability, and conserves the associated natural resources. The SPSs ensure sustainable use of water resources by increasing water use efficiency. The hydroponics cultivation system had 11 ± 1.7 times higher yields but required 82 ± 11 times more energy in comparison to the lettuce crop produced by the conventional production system (CPS). The result of the optimal solution shows that the total revenue of scenarios of the study is 109% of the revenue of the original value of the largest farmer. The water resources and the investment cost as constraints in the model are totally used, but the operational costs in the optimal solutions are 74% of the total operational cost in the original data. The optimal solution showed the importance of using computerized systems in which the control of the fertigation is better.

Keywords: soilless systems; hydroponic technique; linear programming model; water scarcity; water use; economic efficiency

1. Introduction

Nations facing scarcity in natural resources, particularly those grappling with water shortages, are encountering significant economic and social developmental hurdles. In 2012, approximately 40% of the global population experienced water scarcity, and by 2015, approximately 800 million individuals endured hunger [1]. Conversely, climate change is spurred by factors such as alterations in land use, population expansion, industrial and agricultural advancements, and heightened energy usage [2]. Consequently, countries confronted with a deepening scarcity of natural resources are compelled to urgently devise pragmatic solutions spanning various economic sectors.

The agricultural sector assumes a pivotal role in national well-being and the assurance of food security. The 2015 Sustainable Development Summit witnessed United Nations Member States embracing the 2030 Agenda for Sustainable Development, which encompassed a suite of seventeen Sustainable Development Goals (SDGs). These objectives aimed at eradicating poverty, mitigating greenhouse gas emissions, and embracing sustainable strategies for climate adaptation by 2030 [3]. The attainment of these sustainable development goals hinges on the presence of a robust and enduring agricultural sector, acknowledging the influence of agricultural practices on local ecosystem services and the global environment [4]. Within the realm of agriculture, water shortages curtail the capacity to sustain per-capita food production while simultaneously fulfilling water needs for domestic, industrial, and environmental purposes [5].

Sustainable agriculture is characterized by farming systems that endeavor to optimize available technologies and expertise to bolster profitability for stakeholders, all the while ensuring the potential for forthcoming generations to enjoy comparable benefits [6]. Consequently, an imminent necessity emerges to explore technological advancements geared towards augmenting food production in tandem with escalating demands, while simultaneously alleviating pressure on natural resources, notably water and arable land. As an integral facet of sustainable development, sustainable irrigation must achieve dual objectives: maintaining irrigated agriculture to secure food supply and conserving the interconnected natural environment [3].

Numerous studies have probed the efficient utilization of water and diverse irrigation systems. For instance, Momvandi et al. [7] discerned factors impacting the adoption of pressurized irrigation systems by farmers, revealing predictors influencing farmers' behavior and indicating a positive and significant correlation with pressurized irrigation usage. In a similar vein, Fan et al. [8] scrutinized the influences of multiple factors on farmers' decision-making and the economic efficiency of irrigation water use. They found that elevated surface water costs don't effectively reduce water consumption, while groundwater costs correlate positively with water use in corn and soybean cultivation. The integration of pressure irrigation systems reduces soybean water use and elevates soybean yield. The authors concluded that embracing advanced irrigation systems enhances economic irrigation water use efficiency in both corn and soybean farming contexts. Borsato et al. compared three irrigation systems—drip irrigation and two sprinkler systems—in terms of their environmental, economic, and energetic performance under irrigated and non-irrigated maize cultivation. Their analysis combined impact and efficiency indicators, culminating in a sustainability assessment of the irrigation practices across the three systems. Notably, the center pivot system emerged as the optimal solution, demonstrating superior economic and environmental performance. Additionally, maize cultivated under the pivot system exhibited heightened biomass production, economic gains, and water use efficiency [9]. Liu et al. introduced two indices—physical water-saving efficiency and economic water-saving efficiency—to evaluate the effectiveness of inter-regional virtual water flows pertaining to crop trade in China. Their findings highlighted significant virtual water flows attributed to oil-bearing crops, cereals, and beans. Only cereals and vegetables exhibited negative values in terms of physical efficiency. While various crop trades proved economically efficient, most crops' economic water-saving efficiency remained below a specific threshold. The study proposed that adopting advanced water-saving technologies, cultivating novel crop varieties, adjusting regional cropping patterns, and redefining consumption and trade patterns could amplify water savings and enhance physical water-saving efficiency. While pursuing such strategies, potential tradeoffs within social, economic, and environmental realms should be concurrently addressed. The study also advocated water right trading and virtual water compensation to bolster sustainable water consumption, while recommending the implementation of full-cost pricing in the future [10].

Various other research studies have provided insights into adapting agricultural planting and water management practices to cope with a warming environment. Wu and his colleagues examined the effects of temperature rise on water balance components in the groundwater–soil–plant–atmosphere continuum and crop growth. Two experiments involving maize were conducted: one subjected to a 2 °C temperature increase (T-warm) and another under ambient temperature conditions (T-control). The growing season shortened from 125 days in the T-control scenario to 117 days with 2°C warming. Clear reductions were observed in leaf area index (LAI), while mean stem diameter, crop height, and leaf chlorophyll content experienced insignificant declines in the T-warm experiment compared to T-control. Notably, maize grain yield and water-use efficiency both saw increments of 11.0% and 11.1% in the T-warm experiment, primarily attributed to enhanced growth during the sixth leaf to tasseling–silking stage [11]. Meanwhile, Nemeskéri and colleagues examined spectral reflectance at various levels, the leaf area index during developmental stages, and their correlation with yield and nutritional quality. They cultivated three super-sweet corn hybrids with differing ripening characteristics under three water supply conditions: regular irrigation, deficit-irrigation, and unirrigated. Under unirrigated circumstances, plant height, diameter, weight of ears per plant, and total carotenoid content of the kernels all decreased [12].

Others have endeavored to identify risk-efficient farming systems suitable for farmers in central and northeast Thailand. The findings indicated that for extremely risk-averse rain-fed farmers in the central region, maize followed by sorghum constituted the most suitable risk-efficient farming system. In the same region, intensive planting of wet rice and dry rice cultivation emerged as preferences for extremely risk-averse farmers. Similarly, in the north-east region, the combination of wet rice, cassava, and small-scale cattle raising was found to be the most economically viable farming system. On the other hand, extremely risk-averse irrigated farmers in the north-east leaned towards cultivating two rice crops in conjunction with cattle raising [13]. Pedersen and his collaborators presented a comprehensive methodology that facilitates understanding investments, costs, and benefits, offering an overview of the most feasible pathways for implementing precision agriculture. This approach includes diverse scenarios along with their financial and environmental performance, either as single technologies or as a blend of different technologies. Among the key outputs, the analysis yields the net present value of selected environmental indicators in comparison to conventional practices from similar technologies. Their findings suggest that precision agriculture primarily benefits large-scale farms [14].

Further investigations have also assessed resource use efficiency. For instance, a study evaluated the productivity and resource use efficiency of various bioenergy crops and cropping systems using experimental and simulation modeling-derived data. The field experiment, spanning two years and differing soil conditions, explored diverse cropping systems and increasing nitrogen supply. The results indicated that optimized rotations, as alternatives to continuous maize cultivation, demonstrated promising biomass productivity, albeit with trade-offs concerning water and nitrogen use efficiency [15].

Amid these inquiries, the Soilless Production System (SPS) emerges as a practical approach to irrigation water management, thus contributing to food security. Soilless cultivation encompasses methods of growing plants sans soil as a medium for rooting, with nutrients for crops dissolved in an appropriate volume of irrigation water. This technique enhances water use efficiency and crop productivity, thereby making a valuable contribution to climate change adaptation [16].

The current research zeroes in on optimizing the application of SPS and determining the most effective soilless techniques for diverse crops within a study area characterized by limited land and water resources. The study seeks to address pivotal questions such as identifying the most efficient soilless techniques, determining which methods minimize water usage while maximizing revenue, and discerning disparities in water usage among different practices. The study's database was compiled through a 2017 farm survey conducted in Jordan, an arid and semi-arid region. This region faces the challenge of severe water scarcity, with Jordan ranking as the world's second-most water-deficient country, holding merely 88 cubic meters of water per capita. In Jordan, the demand for water far exceeds its supply. For instance, in 2015, the estimated water deficit in Jordan stood at 160 million cubic meters, projected to increase to 490 million cubic meters by 2025. Notably, about 64% of water consumption in Jordan is attributed to the agricultural sector in the Jordan Valley and highlands. Given this context, the pronounced gap between water availability and demand, compounded by scarcity of natural land resources and the pressing issue of climate change, accentuates the urgency of the water problem. In this light, the study aims to evaluate the viability of SPS as a means for sustainable irrigation, estimate water use efficiency within SPS production systems, analyze optimal resource utilization to maximize SPS total revenue while minimizing costs, and ultimately identify the most advantageous practices among different soilless techniques.

2. Material and methods

2.1. Data collection

This study relied on a combination of secondary and primary data sources. The secondary data encompassed information drawn from various research studies, existing literature, and investigations within the domain of soilless production systems. This data was employed to elucidate the characteristics of the soilless system and provide a concise overview of the advancements within this field.

Primary data, on the other hand, was procured directly from farmers participating in a case study. These farmers were actively engaged in the "hydroponic green farming initiative program" (HGFI) and were practicing soilless systems. The case study's farm selection, geographical locations, and comprehensive farmer data were facilitated by the HGFI. The study engaged a sample of 32 respondents, constituting approximately 80% of the total population of 40 farms during the year 2017. The participating farms embraced diverse soilless cultivation techniques and cultivated a variety of crops across different governorates in Jordan. Additionally, all the farms involved utilized protected greenhouse facilities.

The primary data was collected through a well-structured questionnaire that was administered to the farmers practicing soilless production systems. This questionnaire gathered information related to the production process, including details about the type of crops cultivated, the area under cultivation, the specific type of soilless production system utilized (both closed and open systems based on fertigation units), the substrate media employed, the number of planting seasons per year, the quantity of water employed for crop irrigation, and the productivity achieved per plant. Furthermore, the questionnaire also encompassed data on the costs associated with the cultivation system, encompassing both investment and operational costs.

2.2. Description of Soilless Production System (SPS)

The Soilless Production System (SPS) can be classified into two primary categories: The first, hydroponics or water culture, involves fully submerging plant roots in a nutrient solution, such as NFT culture. The second, substrate culture (organic or inorganic source), entails cultivating crops in a solid medium, inert or non-inert, rather than soil. Plants receive nutrients through irrigation in the medium, and any excess solution is allowed to either go to waste or be reused for irrigation. Examples of media include inorganic options, natural materials like sand, gravel, perlite, zeolite, volcanic tuff, etc., synthetic materials, and organic substances like sawdust, peat, coco-soil, park, etc. [17].

Hydroponics is recognized as a notably productive method with remarkable resource efficiency, particularly in terms of water and land usage. The soilless culture technique offers key advantages, including mitigation of soil-borne infections and pathogens, precise control over growth conditions to meet optimal plant needs, resulting in enhanced yields, improved efficiency of water and fertilizer usage, and the potential for agricultural development even in areas with limited arable land [18]. Apart from their water and fertilizer efficiency, soilless farming methods have a small spatial requirement, are conducive to effective disease management, and can be mechanized. Soilless culture is considered a viable approach to prevent soil-borne diseases, salinization, and alterations to physical-chemical properties that could impact final crop yields. However, soilless systems are also associated with certain drawbacks, including high initial capital costs, a need for skilled labor, and requirements for good water quality, factors that often restrict its application to high-value cash crops [19].

The adoption of soilless cultivation techniques using growing substrate media necessitates advanced skills and knowledge from farmers. This is why the open soilless system is often more practical than the closed system due to its lower setup costs and straightforwardness. However, the open system can, under certain conditions, pose a risk of groundwater contamination. In response, a group of researchers conducted a program aimed at enhancing closed soilless systems by utilizing local substrates. These techniques resulted in reduced water and fertilizer loss, while simultaneously minimizing operational costs and environmental pollution [20].

The irrigation systems employed in soilless systems can be categorized based on the technique of delivering water to plants: overhead systems, drip irrigation systems, and sub-irrigation. Excess solution can serve as irrigation for open field plants instead of being released into the environment. In a closed soilless culture system, the surplus solution is collected and recycled [16].

In a study conducted by [21], lettuce crops grown in two different cultivation systems (hydroponic and conventional cultivation) were examined to underscore their land, water, and energy requirements. The findings revealed that hydroponic cultivation systems yielded 11 ± 1.7 times more produce but demanded 82 ± 11 times greater energy compared to lettuce crops grown through conventional practices. This study emphasized the significance of the energy aspect in assessing the sustainability of hydroponic cultivation, while also addressing the issue of water scarcity by suggesting renewable energy solutions (e.g., solar, geothermal, or wind power), making it an appealing prospect for hydroponic systems.

Urban hydroponics enables individuals to cultivate vegetables on flat roofs or small plots within housing areas. It serves as an excellent approach for ornamental growth, enhancing outdoor spaces, greening walls and roofs, producing household vegetables, and generating extra income through surplus food sales [22]. The idea is that urban cultivation, adopting diverse production techniques with ecological, economic, and social considerations, contributes to global food production. About 100 million individuals worldwide embrace urban cultivation, predominantly growing vegetables yielding at least 50 kg/m2/year, thus supporting global food security. Furthermore, organoponics, a subset of hydroponics involving organic nutrient fertilizers, will continue to play a significant role in sustainable food production due to its efficient resource utilization. Incorporating urban cultivation practices into educational and social programs is recommended to enhance population nutritional status and food security [23].

Engindeniz and Gül [24] conducted a study aimed at estimating the costs and returns of soilless protected house cucumber cultivation, intending to provide a sample budget for growers in Turkey. The researchers analyzed the economic aspects of soilless and soil-protected houses for comparative purposes. Total costs were subtracted from total gross income to determine the net return from soilless and soil-protected house cucumber production. The net return from cultivating cucumbers in a blend of perlite and zeolite was determined to be € 1.84 m-2, compared to € 1.48 m-2 in a soil-protected house.

2.3. Modeling

The linear programming (LP) is used to analyze the data and find out the results. The LP is a systematic method of determining the optimal input-output ratio so as to maximize income and minimize cost [25]. This model is used because using LP allows to consider different practices of soilless techniques and gives which one is the best by maximizing the revenue and minimize water use under specific constraints. The validation of the model was done in such a way that a linear programming model for one year was applied to the year of the survey. The model results are compared with the real survey results. The closer the model results are to the survey results, the higher the level of validity [26].

The programming model, which has been used in this analysis, can be mathematically presented as follows:

Objective function $$MaxZ = \sum_{j=1}^{n} R_j X_j \quad (1)$$

s.t. $$\sum_{j=1}^{n} aijX_j = bi, \qquad \text{all I = 1 to m} \quad (2)$$

$$Xj \geq 0 \qquad \text{for each} \qquad j = 1, \ldots\ldots, n \quad (3)$$

Where: Z = the objective function (total revenue); Xj = unit of activity of j-th farmer; Rj = the revenue of j-th farmer; n = number of farmers; m = number of constraints; aij = technical coefficient (amount of i input required to produce one unit of j activity); bi = available amount of i-th constriant.

The analysis focused on three distinct scenarios: Scenario A (All Farmers, All Seasons): In this scenario, the aim was to identify the optimal resource utilization for various crops and planting systems adopted by each individual farmer in the survey, spanning all planting seasons. The maximum available quantity of resources within the model equated to the cumulative resources expended by all surveyed farmers throughout the year. Constraints within the model were defined by the overall resource utilization of all farmers across all seasons. The objective function factored in revenue for each farmer, accounting for the number of planting seasons they practiced. Scenario B (All Farmers, One Season): In this scenario, the objective was to determine the optimal resource allocation for different crops and planting techniques employed by each farmer, considering a single planting season. The upper limit of resources in the model represented the collective sum of resources utilized by all surveyed farmers for a single season. This scenario determined the land area allocated to each crop, assuming a single planting season for each crop. The objective function incorporated revenue and operational costs corresponding to one season per farmer, irrespective of the number of planting seasons they pursued annually. Scenario C (Largest Farmer—All Seasons): In this scenario, the focus was on finding the optimal solution for maximizing revenue while minimizing resource usage, using the resource availability comparable to the largest farmer's utilization for all planting seasons. The model's resource availability was set to match that of the largest farmer surveyed. The objective function integrated revenue calculations for each farmer, accounting for the number of planting seasons per year and the specific techniques applied by the respective farmers.

This scenario aimed to determine the best resource utilization strategy by considering various crops and planting systems embraced by each farmer, provided the maximum available resource quantity aligned with the largest farmer's resource usage across all annual planting seasons.

3. Results and discussion

3.1. The practices of SPSs in the study area

Out of the total of 32 farmers who participated in the survey, 26 were engaged in cultivation using substrate media. The growing media used fell into two categories: inorganic media such as perlite, zeolite, and tuff, or organic media including peat moss and coco-peat. The remaining farmers practiced hydroponic cultivation, wherein water served as the growing medium for the crops they planted.

The findings indicated that various crops were cultivated in the SPS farms, including tomato, sweet pepper, cucumber, lettuce, basil, thyme, parsley, coriander, mint, cantaloupe, strawberry, Rosa sp., and lillium. Strawberry cultivation, a notably high-value cash crop, occupied the largest portion of the farm's area at approximately 86.8%. This underscores the effectiveness of soilless systems for strawberry production. Other crops such as basil, tomatoes, and Rosa sp. covered around 3.8%, 3.16%, and 3.3% of the farm area, respectively, while the remaining crops collectively occupied less than 1% of the total area.

The type of drainage utilized in SPSs determines the system's nature, whether open or closed. In Jordan, about 88% of SPSs are configured as closed systems. This proportion signifies a positive developmental indicator from a sustainability standpoint. While the open soilless system is more straightforward due to its lower establishment cost, the closed system emerged as the preferred choice for protected agriculture adaptation. Its simplicity, recyclability of most components, efficient water conservation, and capability to reduce the release and accumulation of agrochemicals into the environment contributed to its preference [16].

3.2. Water use efficiency in SPSs

This study evaluated the efficient use of irrigation water in SPSs using two key indicators: the average water quantity utilized by SPS farms (m^3/du/y, where du represents dunum or 1000 m^2) and irrigation water productivity (kg/m^3). Comparative analyses were conducted between SPSs and conventional production systems (CPS). Data for CPS farms were obtained from the agricultural credit corporation's greenhouse cultivation manual for 2014 [27], while water usage information for SPSs was gathered from survey results.

For the strawberry crop cultivated in closed SPS farms, the average irrigation water usage was around 341 m^3/du/y, whereas the strawberry crops in CPS farms consumed nearly three times that amount. Similarly, vegetable crops such as tomato and cucumber utilized 300 and 1220 m^3/du/y, respectively, in SPS cultivation. In comparison, if these crops were grown in CPS, the water consumption figures would have been 1100 and 3000 m^3/du/y for tomato and cucumber, respectively. These results highlighted significantly lower irrigation water consumption in SPSs compared to CPSs (Figure 1).

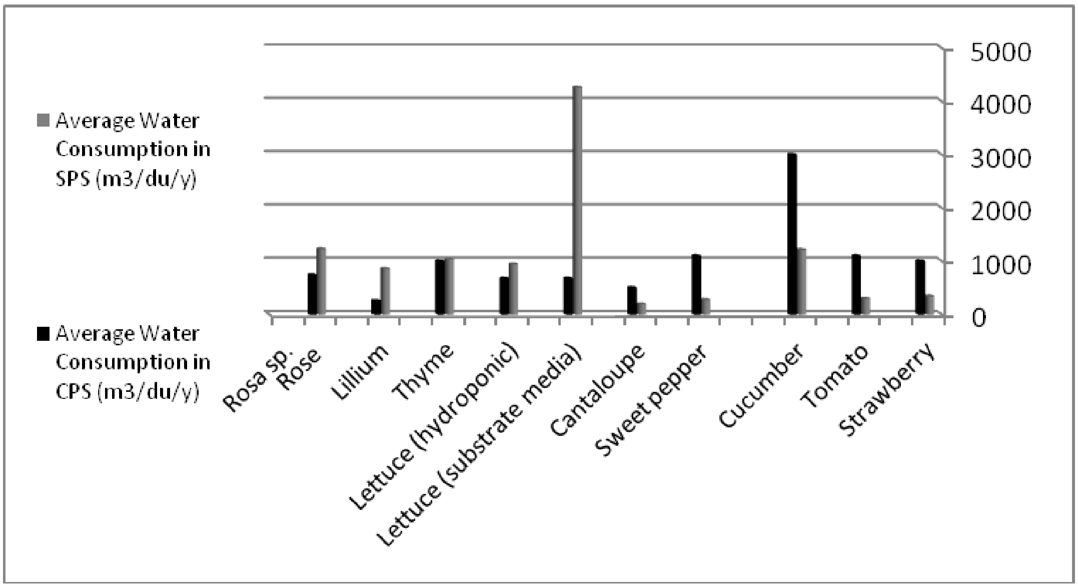

Figure 1. Average water consumption in SPSs and CPS (m^3/du/y).

There was a huge growth in productivity of 1 m^3 water in the strawberry crop when it was cultivated on the SPS at 25 kg/m^3 in comparison with 3 kg/m^3 productivity when cultivated on the CPS. Also for tomato and cucumber, the irrigation water productivity in the SPSs was 20.6 and 25.20 kg/m^3 respectively. While the irrigation water productivity for the same crops cultivated in the CPS was 9.1 and 10 kg/m^3 respectively (Figure 2).

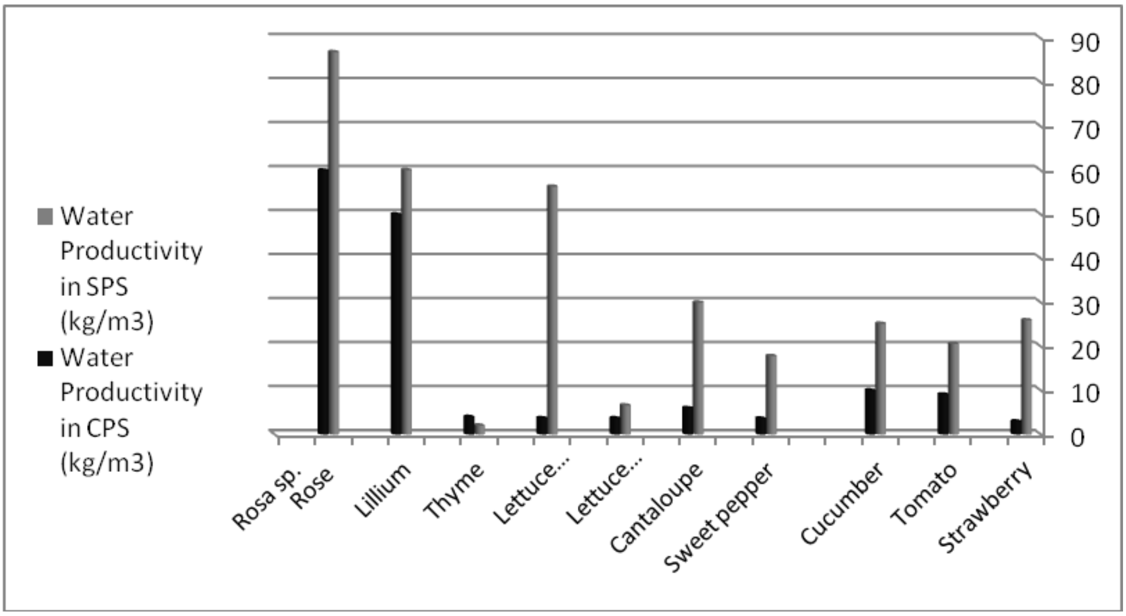

Figure 2. Water productivity in SPSs and CPS (kg/m^3).

Regarding leafy vegetable crops like lettuce, which were cultivated using substrate media in closed SPSs, the irrigation water consumption amounted to 4263 m3/du/y. In contrast, lettuce cultivated in CPS required 675 m3/du/y. This difference is attributed to the fact that lettuce grown in SPSs experienced an increase in the number of growing seasons per year, reaching seven seasons, whereas CPS cultivation had only one season. Furthermore, the irrigation water productivity in SPSs was measured at 6.6 kg/m3, while the corresponding figure in CPS was 3.7 kg/m3. The outcomes related to average irrigation water quantities and productivity underscore the sustainability of adopting SPSs as an irrigation practice [2]. This approach enhances water use efficiency, fosters profitability, and safeguards natural resources. These findings should motivate the government to intensify efforts in maintaining food production while implementing stringent management of freshwater resources.

3.3. Mathematical models for different scenarios

The estimated total revenue derived from survey results for all farmers within the study area (around 32 farmers) amounted to 42 million JD (approximately 59 million US dollars), with a per-hectare total revenue of 274 thousand JD. The optimal solutions of scenarios A and B, derived from the mathematical models, indicate that in scenario A, the total revenue reaches 133% of the original value (as obtained from the survey) by utilizing the entire survey area of 153.5 hectares. This scenario capitalizes on an increased number of seasons per year in the model, resulting in a total revenue of 55 million JD. If the model runs with one season per year, as in scenario B, the optimal solution generates a total revenue of 48 million JD. In both scenarios, the water resources that were constraints within the model are fully utilized. Remarkably, the operational costs in the optimal solutions for both scenarios experienced a decrease of 65%, with farmers utilizing 77% of the total operational costs (see Table 1). This dynamic implies that the implementation of the results from these two scenarios could lead to increased total revenue and decreased operational costs [24].

Table 1. The results of scenarios A and B.

	Survey results	Results of Scenario A	The ratio of the model of scenario A results to the survey results (%)	Results of Scenario B	The ratio of the model of scenario B results to the survey results (%)
Total Revenue (JD)	42026053	55875349	133%	48415129	115%
Constraints					
Water Quantity (m^3)	644841	644841	100%	644841	100%
investment cost (JD)	9506134	9506134	100%	9506134	100%
Operational cost (JD)	8636401	5593324	65%	6614248	77%
Cultivated area (Ha)	153.5	153.5	100%	153.5	100%
No. of green houses	2827	2566	91%	2827	100%
Total revenue per unit of area (JD/Ha)	273782	364004	133%	315404	115%
Operational cost per total revenue (JD/JD)	0.21	0.10	48.7%	0.137	66.5%
Investment cost per total revenue (JD/JD)	0.23	0.17	75%	0.196	86.8%
Total revenue per unit of water (JD/ m^3)	65.17	86.65	133%	75.08	115%
Quantity of water (m^3) per unit of green house	93.4	102.9	110%	93.4	100%

Utilizing the soilless system, as demonstrated in scenarios A and B, yields remarkably high revenue per unit of area (one hectare), amounting to 364 thousand JD and 315 thousand JD (514 and 445 $) in the optimal solutions of scenarios A and B, respectively. However, the investment costs in scenarios A and B constitute around 17% and 20% of the total revenue, respectively, a significant improvement compared to the 23% observed in the original data. Similarly, the operational costs in scenarios A and B account for approximately 10% and 14% of total revenue, while the original data places it at 21% of total revenue. Consequently, it becomes feasible to recover the total cost within the initial year, with an added net income of about 73% of total revenue in scenario A and roughly 66% of total revenue in scenario B. This underscores the substantial advantage of achieving financial sustainability in water-scarce regions, as the total revenue per unit of water (one cubic meter) reaches around 87 JD and 75 JD in scenarios A and B, respectively, far exceeding other systems. The principal distinction between Scenario A and Scenario B lies in the consideration of the number of seasons per year. In these scenarios, the mathematical model provides the flexibility to utilize the same greenhouse for planting multiple times within a year. As indicated in Table 1, such an approach, as seen in Scenario A, leads to amplified total revenue, reduced operational costs, and a smaller land area requirement. This multifaceted benefit accentuates the advantages of employing SPSs, particularly in low-income countries. Additionally, in cases where water availability is limited, the potential for income augmentation by engaging in multiple planting seasons is notably high.

In scenario C, the model takes into account the maximum investment cost and the maximum area, mirroring those employed by the largest farmer within the survey. This equates to a maximum area of 70 hectares and a maximum investment of 2.67 million JD, as depicted in Table 2. For the largest farmer, their revenue amounts to 18 million JD. The model's outcomes reveal that the total revenue across all scenarios is 109% of the original value pertaining to the largest farmer. Although the water resources and investment costs function as constraints within the model, they are fully utilized. However, the operational costs within the optimal solutions constitute 74% of the total operational cost as compared to the original data.

Table 2. The results of scenario C.

	Survey Results	results of Scenario C	% The results of the model of scenario C to the results of the survey results
Total Revenue (JD)	18480000	20144947	109%
Constraints			
Water Quantity (m^3)	189000	189000	100%
Investment cost JD	2665000	2665000	100%
Operational cost (JD)	3489300	2592141	74%
Cultivated area (Ha)	70	62	88.5%
Green houses (No.)	1400	1234	88%
Total revenue per unit of area (JD/Ha)	264000	325094	123%
Operational cost/total revenue (JD/JD)	0.1888	0.129	68%
Investment cost per total revenue (JD/JD)	0.144	0.132	92%
Total revenue per unit of water (JD/m^3)	97.78	106.59	109%
Quantity of water m^3 per unit of green house	135	153.2	113%

In scenario C, the revenue per unit of area (one hectare) reaches 325 thousand JD. The investment cost constitutes approximately 13% of the total revenue, and the operational cost within the optimal solution accounts for about 14% of the total revenue. This implies that the entire cost could be recuperated within the first year, along with an additional net income of about 73% of the total revenue. Notably, the total revenue per unit of water (one cubic meter) is roughly 105 JD, reflecting the minimal water consumption within the system (as detailed in Table 2). The findings underscore the high potential for total revenue increase and operational cost savings, particularly for farmers with limited resources, such as the largest farmer studied [17].

The outcomes further reveal that SPSs embraced a soilless approach, utilizing diverse types of growing media, including coco-peat, tuff, peat moss, zeolite, and perlite. In order to highlight the optimal practices of the farmers, a summary of these practices is presented in Table 3. The prominence of strawberry cultivation is evident across various optimal solutions for distinct scenarios. The closed system emerges as a pivotal choice for most farmers, primarily due to its water-saving advantages over the open system. Furthermore, the majority of farmers within the optimal solutions employ computerized systems, enhancing their control over fertigation processes. In terms of growing media, the optimal solution for all scenarios commonly features the utilization of cocopeat, water, and tuff.

Table 3. The different soilless practices in the optimal solutions of different scenarios.

Farmer No.	Crop	Area (Ha)	Irrigation system	Growing media	Fertigation system
Scenario A					
3	Strawberry	93.91	Closed	Coco-peat	Computerized
19	Red lettuce	34.21	Closed	Water	
17	Basil	25.38	Closed	Tuff	Computerized
Scenario B					
3	Strawberry	131.37	Closed	Coco-peat	Computerized
27	Rosa spp.	7.32	opened	Tuff	Semi computerized
16	Basil	6.09	Closed	Water	Manual
17	Basil	8.71	Closed	Tuff	Computerized
Scenario C					
3	Strawberry	56.11	Closed	Coco-peat	Computerized
19	Red lettuce	5.86	Closed	Water	Computerized

4. Conclusions and recommendations

The implementation of Soilless Production Systems (SPSs) contributes to the sustainable utilization of water resources by enhancing water use efficiency. The adoption of soilless techniques leads to an enhancement in crop productivity and a reduction in the strain on water supplies. As a result, this approach stands as an environmentally sustainable solution, benefiting water conservation, maintaining soil productivity (preventing erosion and soil degradation), and minimizing the need for fertilizers.

The profitability per unit of water volume is notably high when employing soilless techniques, indicating the appropriateness of this method for countries facing water scarcity. SPSs not only elevate production yields while keeping expenses in check but also exhibit strong economic viability. The potential advantages of cultivating multiple crops within a year hold significance for both arid regions and areas with limited water resources.

Analyzing the optimal outcomes across various scenarios underscores the substantial potential to lower operational expenses and simultaneously augment total revenue with the available resources. This potential improvement indicates a substantial enhancement in the living standards of farmers in regions affected by water or land scarcity. It's worth noting that the substantial investment and operational costs underscore the necessity for financial support for small-scale farmers.

However, determining the most effective combination of techniques requires a comprehensive examination of the mathematical model results presented in this study. These outcomes are contingent upon the methods currently employed by farmers on their lands. To further these goals, environmental protection agencies and sustainable agricultural organizations should collaborate on long-term research and extension initiatives. These initiatives should aim to comprehend the cumulative impact of soilless farming on land, water sources, the environment, and the national economy. Simultaneously, they should foster and endorse the development of agricultural practices that not only enhance environmental quality but also sustain economic viability and the well-being of communities.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflicts of Interest

The authors declare no conflict of interest.

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