Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2022.28215

263 (2022) 116–124
July

Economic and environmental evaluation of different irrigation systems for date palm production in the GCC countries: the case of Oman and Saudi Arabia

Boubaker Dhehibi[a,*], Mohamed Ben Salah[b], Aymen Frija[a], Aden Aw-Hassan[c], Hamdane Al Wahaibi[d], Yousuf Al Raisi[d], Ahmed Zakaria Dewidar[e], Yousef Al Fuhaid[f], Arash Nejatian[g], Abdoul Aziz Niane[g]

[a]*Resilient Agricultural Livelihood Systems Program (RALSP), International Center for Agricultural Research in Dry Areas (ICARDA), Tunis, Tunisia, emails: b.dhehibi@cgiar.org (B. Dhehibi), a.frija@cgiar.org (A. Frija)*
[b]*Arid Region Institue, Gabes, Tunisia, email: a.bensalah@yahoo.fr (M.B. Salah)*
[c]*Resilient Agricultural Livelihood Systems Program (RALSP), International Center for Agricultural Research in Dry Areas (ICARDA), Cairo, Egypt, email: aawhassan@gmail.com (A. Aw-Hassan)*
[d]*Ministry of Agriculture & Fisheries, Muscat, Oman, emails: hamdanssw@outlook.com (H. Al Wahaibi), yousufalraisi@outlook.com (Y. Al Raisi)*
[e]*College of Food and Agriculture Sciences, King Saud University, Kingdom of Saudi Arabia, email: adewidar@ksu.edu.sa (A.Z. Dewidar)*
[f]*Date Palm Research Center in Al-Hassa, Ministry of Agriculture, Kingdom of Saudi Arabia, email: Yousuf_alfuhaid@yahoo.com (Y. Al Fuhaid)*
[g]*Arabian Peninsula Regional Program, International Center for Agricultural Research in the Dry Areas (ICARDA), Dubai, UAE, emails: a.nejatian@cgiar.org (A. Nejatian), a.niane@cgiar.org (A.A. Niane)*

Received 28 February 2022; Accepted 28 April 2022

ABSTRACT

This study evaluates the irrigation water volumes' effect on the date palm productivity and water use efficiency under several conventional and improved irrigation systems (surface, subsurface, bubbler, subsurface drip irrigation). The study is focusing on Oman and Saudi Arabia. Data on the water requirement, temperature, and evapotranspiration has been collected from the experimental study conducted at Al-Kamil and Al-Wafi Agricultural Research Station, Oman and Farm Al Briga – research station, Kingdom of Saudi Arabia. The socioeconomics data used was collected from several national and international sources. The partial budgeting method is used for economic comparison between different irrigation systems. In Oman, the performance of bubbler irrigation systems (BI) and subsurface drip irrigation systems (SDI) was studied in terms of water use efficiency, economic performance, and yield of date palms (Cv. *Khalas*). Three intervention levels on SDI have been used: at the rate of 60%, 40%, and 20% of water requirement. This experimental study showed that SDI under the three intervention uses water more efficiently than the BI system. The water use efficiency (WUE) of the SDI 20%, 40%, and 60% of water requirements were 2.0, 2.7, and 4.7 kg/m^3, respectively. Meanwhile, the BI water use efficiency was 1.3 kg/m^3. Economic findings confirmed using the SDI method vs. the BI method increased the cost of establishment but is economical in the long term. Therefore, measures can be taken to reduce the cost of equipment by promoting the production and supply of low-cost SDI systems. In Kingdom of Saudi Arabia, surface drip (SD) irrigation and SDI performance were evaluated in terms of water use efficiency, economic viability, and date palms

* Corresponding author.

Presented at the 14th Gulf Water Conference: Water in the GCC… Towards Economic Efficiency and Financial Sustainability, 13–15 February 2022, Riyadh, Saudi Arabia

yield (Cv. *Khalas*). The results showed that SDI was more efficient in comparison to the drip irrigation (DI) technology. The SDI could save about 27% of irrigation water compared to SD. The results also confirmed that the SDI system produced the same date palm yield while saving the irrigation water. Findings indicate that the SDI compared to the DI could save between 125 and 205 $/ha. This result suggests water economic profitability by using the SDI system in date palm farming. These findings indicate a significant difference in net profit. Overall, the adoption of modern irrigation techniques such as drip and subsurface drip irrigation is essential today for this very arid region. This is mainly to increase WUE and Yield. In a short time, the capital cost associated with installing such a system limits adopting this technology. Thus, to accelerate the adoption process of these technologies, it is imperative to create favourable conditions so that a more significant number of farmers can benefit from the benefits of such technologies. The creation of strong networking among different institutions related to applying this modern irrigation technology and public and private financial institutions and support services could be an example of mechanisms to enhance adoption.

Keywords: Economic evaluation; Environmental evaluation; Irrigation systems; Oman; Kingdom of Saudi Arabia

1. Introduction

The project "Development of Sustainable Date Palm Production Systems in the GCC Countries of the Arabian Peninsula", funded by the GCC Secretariat, was implemented, in partnership, by ministries of agriculture, agricultural authorities, and agricultural research institutions and universities in the six GCC countries of the Arabian Peninsula (Kingdom of Bahrain, United Arab Emirates, State of Kuwait, State of Qatar, Sultanate of Oman, and Kingdom of Saudi Arabia) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The project's primary objectives are to improve date palm productivity per unit of water and rationalize the available resources so that production becomes sustainable. The project also aims to: (i) define the nutritional requirements for the optimal growth of date palm through leaf tissue and soil analysis and establish the need to use macro and micronutrients; (ii) to improve date palm field practices and management for a vigorous tree with a high yield and better fruit quality at harvest; (iii) to develop sustainable and ecologically sound integrated pest management systems that reduce crop losses caused by significant pests and diseases and increase the quality and market value of the dates; (iv) to establish efficient post-harvest management protocols, including processing, marketing, and the use of a date palm value-added products; (v) to assemble a set of tools to enable researchers, extension workers, and growers to share the accumulated information, knowledge, and expertise, and strengthen national institutions and human resource capacity and enhance technology transfer. Within this project framework, researchers succeeded in introducing one promising technology: the subsurface drip irrigation. This technology has the advantage of potential water savings, and date palm yield increases. It has the potential to be the most efficient irrigation method available today. It is considered one of the most attractive and promising technologies for the Arab States of the Gulf countries, a region defined as the poorest in terms of water resources where arid conditions in these countries act as a natural constraint expansive agriculture. The objective of introducing this technology is to provide water application strategies that maximize yield, minimize water loss for a range of irrigation system designs, and apply for date palm farmers in the GCC countries. Therefore, while developing improved technologies is essential for farmers in rural livelihoods for this region, new technologies can positively affect livelihoods if they are profitable and adopted by farmers. In light of these challenges, this study's main objective is to evaluate the irrigation water volumes' effect on the date palm productivity and water use efficiency under several conventional and improved irrigation systems (surface, subsurface, bubbler, subsurface drip irrigation). It is mainly to investigate economically and environmentally the effectiveness of this introduced irrigation system in terms of water use and requirement and yield productivity. This is mainly to compare this irrigation system (SDI) to several conventional irrigation systems used in the GCC countries in terms of water use efficiency and date palm yield productivity. The study is focusing on Oman and Saudi Arabia.

2. Date palm irrigation systems in Oman and Kingdom of Saudi Arabia: an overview

2.1. Date palm irrigation systems in Oman

According to Al-Yahyai and Mumtaz Khan [1], irrigation water is traditionally delivered to date palm groves through open canals. Water sources are mainly underground aquifers and wells or via the Falaj – an ancient water system to farms in Oman. Other water sources have also been explored, such as utilizing treated wastewater [2,3], which is only used to a small extend. The timing and frequency of irrigation are mostly dependent on the allocated shares of water for each grove and is not based on empirical methods. Adopting new irrigation methods (such as bubbler irrigation, a localized, low pressure, reliable permanent installation drip irrigation system), particularly in well-irrigated groves, is slowly gaining momentum as the government is subsidizing the installation. Al-Yahyai and Al-Kharusi [4] also reported that chemical quality attributes of date palm (Cv. *Khalas*) grown in northern Oman varied in response to decreased frequency of irrigation water applied during fruit development. Several previous studies indicated that subsurface drip irrigation is a promising technology that contributes to improving water use efficiency and productivity. Besides, it is considered the mosteffectivewaytodirectlyprovidewaterandnutrienttotheplant and increase crop productivity [5–7]. This subsurface drip irrigation represents the recent improvement of irrigation as it significantly reduces losses of direct evapotranspiration, runoff, and deep percolation [8,9]. However, it is necessary to study and examine the performance and the efficiency of this irrigation technology compared with other irrigation systems such as bubbler irrigation systems, which are also being used in these areas. This study's main objective is to examine the efficiency of subsurface drip irrigation system for young palm trees in the Sultanate of Oman in terms of both water use efficiency, yield, and economic viability of this system compared to the existing bubbler irrigation system. Our results will help identify the most efficient technique for water conservation (environmentally and economically) and the most profitable.

2.2. Date palm irrigation systems in Kingdom of Saudi Arabia

Date palm production in arid areas, such as Saudi Arabia, is facing growing physical and quality water scarcity. Surface water resources are becoming increasingly scarce, while groundwater resources, which generally have low quality due to the high salinity levels, are often overexploited. In this context, water-saving became an imperative option for oases sustainability. If drip irrigation is currently recommended in many regions worldwide for saving water, its use in highly arid areas is becoming debatable since it does not keep water safe from high evaporation. The "Development of Sustainable Date Palm Production Systems" project in Gulf Cooperation Council Countries project aims to produce new knowledge and practices to improve date palm production systems in the Gulf countries. The project's main activities include improving the productivity of cultivars, managing natural resources (land and water) for optimal performance, optimizing the use of different inputs in the production process (including fertilizers, pollinators, wastewater, etc.), and studying the genetic diversity of date palms. Technology transfer and experience exchange among partner countries is an integral part of the project.

One promising technology introduced through the project is subsurface drip irrigation. This technique is defined as an application of water under the soil surface through drippers that deliver water at rates generally similar to the surface drip irrigation [10]. The comparison of the water use efficiency (WUE) and performance between different irrigation methods and systems of date palm (drip, flooding, and micro-jet) showed that drip irrigation system is the most efficient, followed by the flood irrigation system and micro-jet [11]. The optimal response of date palm on drip irrigation is due to the system operation in which drippers deliver water slowly for a relatively long period. This process enables better water control and distribution through the soil profile. Therefore, losses due to evaporation and deep percolation are reduced, and the date palm can use almost all of the applied water [12]. The subsurface drip irrigation (SDI) represents a successful irrigation improvement because it is considered the most efficient irrigation technique that significantly reduces water losses of direct evaporation, runoff, and deep percolation [8,9]. The precise application of water and fertilizers resulted in increased water use efficiency, application uniformity of water, and improved crop yield [13]. Besides, it prevents the growth of weeds around the crop [14]. Thus, subsurface drip irrigation is considered the most effective way to directly provide water and nutrients to the plants and increase crops' productivity [15,16]. A well-designed subsurface drip irrigation system provides values of the water use efficiency greater than 95% [17]. More than 95% of the supplied and maintained water in the root zone is beneficial for crops (i.e., date palm trees).

3. Experimental research design framework

3.1. Experimental research design process in Oman

In Oman, the study focuses on the evaluation of four interventions as follows: *Intervention I*: irrigation with bubbler irrigation system at the rate of 100% of water requirements; *Intervention II*: irrigation with subsurface drip irrigation at the rate of 60% of water requirements; *Intervention III*: irrigation with subsurface drip irrigation at the rate of 40% of water requirements; *Intervention IV*: irrigation with subsurface drip irrigation at the rate of 20% of water requirements. Water requirement was calculated based on the evapotranspiration coefficient and using the CROPWAT software. The KC coefficient used in the analysis has an average value of 0.9 for the date palm crop. The monthly water irrigation schedule and the measurements covered the year 2015–2016. The different measures and parameters used in the experience, such as evapotranspiration, crop water requirement, water applied, and total water applied, are detailed in Dhehibi et al. [18].

3.2. Experimental research design process in Kingdom of Saudi Arabia

3.2.1. Cropping details and measurements

Field measurements were taken during the productive cycle of 15 y old date palm trees during the 2015–2016 date palm cropping season. The experimental date palms had an average height of trunk 2.4 m, average trunk diameter of 0.80 cm, average leaf length of 400 cm, and an average number of 55 leaves per palm. The date palms were spaced at 8.0 m for both rows to row and tree to tree. The chemicals and pesticides were applied identically as necessary to all trees. Fertilizers were divided and delivered following farm management practice for palm trees. Date palm yields, yield components, agronomics parameters, and soil water data were determined for both drip irrigation (DI) and SDI systems.

3.2.2. Irrigation system description and scheduling

The date palm trees were separately irrigated with DI and SDI during the study period. The irrigation system consisted of head unit, central and sub-main delivery polyethylene pipes of 75 and 63 mm in diameter. The connected to the sub-main, which leads water to subareas through laterals. The laterals for both SDI and DI systems were 32 mm in diameter. The drippers/

emitters were either placed on the soil surface (DI) or buried at 40 cm soil depth (SDI) in concentric rings around the date palm trees. Trenches were excavated and dressed manually. The date palm trees were irrigated daily with a water volume according to the climatic data acquired from a nearby-automated weather station. The amounts of water were measured at each irrigation event by multi-jet dry type water meters fixed to the sub-main lines. Concerning the schedule of subsurface drip irrigation, around 70% of the water has been added more, as in surface irrigation.

3.2.3. Amount of applied water

The quantity of water applied varied with the period, depending on the atmospheric temperature and other climatic parameters. The quantity of water applied in mm per month is fluctuating between January to December (2015). The minimum and maximum monthly values of irrigation depth added in the initial growth stage through DI and SDI were 91, 185, and 64, 129 mm, respectively. With increasing temperatures starting from April, date palm trees looked more stressed, requiring more frequent irrigations. During the summer (May to July), the amount of water applied to DI and SDI increased to 292 and 204 mm/month, respectively. In the flowering and fruiting stages, the amount of water applied through DI and SDI decreased and fell to 115 and 81 mm, respectively. The following aspects, playing a significant role in influencing evapotranspiration, and consequently in this calculation, have been considered: (1) *Soil salinity*: If the soil is saline, more water must be given to enable a leaching process for clearing the salt from the soil; (2) *Temperature*: The higher the temperature, the higher the rate of evaporation and the more water the plant needs; (3) *Humidity*: The lower the humidity level, the more water needed; (4) *Wind (speed and occurrence)*: Higher constant wind speeds causes higher evaporation and thus higher water demands.

3.3. Methodological framework, data sources, and empirical analysis

3.3.1. Data collection and data sources

Data on the water application, temperature, evapotranspiration has been collected from the experimental study conducted at Al-Kamil and Al-Wafi Agricultural Research Station at South Sharqiyah Governorate, Oman, and from the experimental study conducted at the experimental Farm Al Briga – station at Centre for Date Palm and Dates, Al Hassa, Kingdom of Saudi Arabia. The socio-economic data was mainly collected from several national and international sources.

3.3.2. Water use efficiency

Water use efficiency – WUE was calculated as a ratio between the marketable yield and the seasonal values of actual evapotranspiration using the following equation [19]:

$$\text{WUE} = Y/W \tag{1}$$

where WUE is water use efficiency (kg/m^3), Y is the total marketable date palm yield (kg), and W is seasonal irrigation applied water (m^3).

3.3.3. Economic and statistical analysis

The partial budgeting method is used for economic comparison between both irrigation systems. Data collected was examined statistically by using the analysis of variance procedure from the statistical analysis software (SPSS). To compare treatment means, Fisher's protected least significant difference (LSD) was used for ($p \leq 0.05$) significant level.

4. Results and discussion

4.1. Empirical research findings and discussion: Oman

4.1.1. Economic evaluation: date palm yield

The irrigation interventions on the date palm productivity are presented in the table below (Table 1). The empirical figures displayed in the table below indicate that no significant difference in the date palm productivity under Intervention I, irrigation with bubbler irrigation system at the rate of 100% of water requirements, and Intervention II (irrigation with subsurface drip irrigation at the rate of 60% of water requirements).

Table 1
Date palm productivity under the four irrigation interventions level (kg/tree and kg/ha)

Irrigation intervention type	Yield – experimental irrigated area (kg/tree)	Yield – potential irrigated area (kg/ha)
INTER I: irrigation with bubbler irrigation system (BI) at the rate of 100% of water requirements	79.0	12,956
INTER II: irrigation with subsurface drip irrigation (SDI) at the rate of 60% of water requirements	78.3	12,841.2
INTER III: irrigation with subsurface drip irrigation (SDI) at the rate of 40% of water requirements	69.8	11,447.2
INTER IV: irrigation with subsurface drip irrigation (SDI) at the rate of 20% of water requirements	68.8	11,283.2

Source: Owen elaboration from experimental data – Date Palm Project Team in Oman (2017);
Note: Number of date palm trees/ha (10,000 m^2) = 164.

The productivity level under the first irrigation system is about 79 kg/tree, while it was around 78.3 kg/tree under the second system. However, under the third (irrigation with subsurface drip irrigation at the rate of 40% of water requirements) and fourth intervention (irrigation with subsurface drip irrigation at the rate of 20% of water requirements), the productivity of the date palm – variety *Khalas* decreased to reach an average of 69.8 and 68.8 kg/tree, respectively (Table 3). In general, the difference in productivity between Inter I, Inter II, Inter III, and Inter IV is, on average, for about 0.7, 9.2, and 10.2 kg/tree, respectively. This difference is about 114.8; 1,508.8; 1,672.8 kg per hectare, respectively. At the current market price (0.8 OMR/kg the *Khalas* variety), we note a difference of about US$238.78, US$3,138.30, and US$3,479.42 at the hectare, between the bubbler irrigation (BI) and the three SDI interventions, respectively. However, if we want to evaluate the real return and the net profit, we must consider the cost of water for each intervention in addition to the running costs in each case.

4.1.2. Environmental evaluation: water use efficiency

Empirical findings are presented in the table below (Table 2). Results show that water productivity (kg/m^3) increase with the decrease of water quantity. Findings indicated that the fourth intervention (irrigation with subsurface drip irrigation at the rate of 20% of water requirements) is the most efficient. Empirical findings demonstrate that WUE was significantly increased by 35%, 52%,

Table 2
Quantity of water consumed and saved under the four irrigation interventions level (m^3/ha and US$/ha) – DI vs. SDI

Irrigation intervention	Water use efficiency (kg/m^3)	Total water consumed (m^3/ha)	Total water saved (m^3/ha) BI vs. SDI	Potential water saving (US$/ha) BI vs. SDI Scenario I	Potential water saving (US$/ha) BI vs. SDI Scenario II	Potential water saving (US$/ha) BI vs. SDI Scenario III	Potential water saving (US$/ha) BI vs. SDI Scenario IV
INTER I	1.3	9,966.154	–	–	–	–	–
INTER II	2.0	6,420.6	3,545.554	74.456634	109.912174	145.367714	180.823254
INTER III	2.7	4,239.704	5,726.45	120.25545	177.51995	234.78445	292.04895
INTER IV	4.7	2,400.681	7,565.473	158.874933	234.529663	310.184393	385.839123

Source: Owen elaboration from experimental data – Date Palm Project Team in Oman (2017);
Notes: (1) Number of date palm trees/ha (10,000 m^2) = 164;
(2) *Water pricing scenarios:* the combined capital, maintenance and energy cost of pumping groundwater from a typical dug well for traditional irrigation is estimated at about US$0.021/m^3 (Scenario I) and US$0.031/m^3 (Scenario II) for average conditions. Pumping costs from a tube well for a modem irrigation system, requiring a larger pumping head, are between US$0.041 (Scenario III) and 0.051/m^3 (Scenario IV).

Table 3
Effect of irrigation method on total cost, total return and net profit – variety *Khalas*

Irrigation intervention	Yield – potential irrigated area (kg/ha)	Total return ($/ha)	Total variable costs ($/ha)	Water costs ($/ha)	Net profit ($/ha)
INTER I: irrigation with bubbler (BI) at the rate of 100% of water requirements	12,956	20,211.36	5,857.81	1,224.29	13,129.25
INTER II: irrigation with subsurface drip irrigation (SDI) at the rate of 60% of water requirements	12,841.2	20,032.27	5,857.81	1,349.43	12,825.02
INTER III: irrigation with subsurface drip irrigation (SDI) at the rate of 40% of water requirements	11,447.2	17,857.63	5,857.81	1,260.02	10,739.80
INTER IV: irrigation with subsurface drip irrigation (SDI) at the rate of 20% of water requirements	11,283.2	17,601.79	5,857.81	1,184.62	10,559.36

Source: Owen elaboration from experimental data – Date Palm Project Team in Oman (2017);
Notes: (1) Number of date palm trees/ha (10,000 m^2) = 164;
(2) The market price of the variety *Khalas* is estimated to be 0.8 OMR (2.08$). The total variable costs were estimated at US$5,202.57/ha (Dhehibi et al. [18]). In the total return, we consider only 75% of the production is marketable (25% are considered as waste);
(3) Water costs are calculated using the following estimations: for both irrigation systems (BI and SDI), the irrigation/water cost by hectare includes the equipment cost (depreciation), operating, maintenance cost, and the value of the consumed amount of water.

and 72% in case of subsurface drip irrigation (SDI) under the three intervention levels (60% with WUE = 2 kg/m^3, 40% with WUE = 2.7 kg/m^3, and 20% with WUE = 4.7 kg/m^3) compared to bubbler irrigation (BI with WUE = 1.3 kg/m^3). These findings confirmed that SDI contributes to saving 35% and 72% (depending on the implemented intervention) of irrigation water without decreasing the *Khalas* date palm productivity level. From the environmental point of view, these results suggest that a significant reduction in the volume of water can be achieved when using the SDI system. This amount of water saved by hectare under the three SDI options, 60%, 40%, and 20%, is estimated to be 3,545.554; 5,726.45; 7,565.473 m^3, respectively. At an estimated average price of US$0.041/m^3 of irrigation water, the average dollar value saved by hectare under the three options will be around US$145.36, US$234.78, and US$310.18, respectively. The results outlined in Table 4 reveals the potential cost of saving by using subsurface drip irrigation (under the tree intervention types) in comparison to the bubbler irrigation system (BI). This saving ranges from 74.45 to 385.8 $/ha, according to the SDI irrigation intervention category used. This result suggests that a considerable amount of water (in terms of quantity and value) could be potentially saved by using SDI, and consequently, a more sustainable farming system for *Khalas* date palm variety in the research site, in particular, and, in the Sultanate of Oman, in general.

4.1.3. Economic and financial analysis

Total annual date palm water use will undoubtedly have a significant impact on water costs. Thus, the irrigation method will affect the total return and net profit. We should also indicate that initial cost (equipment and installation) for the SDI system is higher than the BI system. Consequently, we outlined the hypotheses used in this economic analysis: the expected life of both (BI) and SDI systems is 10 y. Results are at the hectare level and per year; The price of 1 m^3 of irrigated water used in the analysis is US$0.041; 1 Omani Rial (OMR) = 2.60$ (average January–March 2017); The average cost of installing bubbler irrigation system (equipment and installation) at the hectare is estimated at 1,963 OMR (which is equivalent to US$5,098.04) ha. The cost of operation and maintenance is estimated at 6% of the equipment and installation cost per ha and year: US$305.88; The quantity of water used for one ha of *Khalas* date palm trees using a bubbler irrigation system is estimated at 9,966.154 m^3. The cost of this water used is around US$408.61; The average cost of installing subsurface drip irrigation (equipment and installation) is estimated at 2,614 OR (equivalent to US$6,788.73). The cost of operation and maintenance is estimated at 6% of the equipment and installation cost per ha and year: US$407.32; The quantity of water used for one ha of *Khalas* date palm trees using subsurface drip irrigation system at the level of 60%, 40%, and 20% of water requirement is estimated at 6,420.6; 4,239.704; 2,400.68 m^3, respectively. The cost of the used amount of water is US$145.36, US$234.78, and US$310.18, respectively. The empirical findings are presented in Table 3. This table shows the irrigation method's effect on water cost, total return, and net profit considered in average values at the hectare level. The results indicated that, under the bubbler (BI) irrigation system, the total return, total variable costs, water costs and net profit were 20,211.36; 5,857.81; 1,224.29; 13,129.25 $/ha, respectively. Besides, we noted a slight difference in net profit when using SDI at the rate of 60% of water requirements. This additional benefit will be about US$12,825.02/ha.

Furthermore, by using SDI at the rate of 40% and 20%, we note a significant difference in net profit compared to the benefit recorded when using the bubbler irrigation method. This difference ranges between 2,389.45 $/ha (SDI at 40% of water requirement) and 2,569.89 $/ha (SDI at 20% of water requirement). This analysis showed that the total return and net profit values of *Khalas* date palm trees increased with the BI irrigation method compared to the SDI (under the three interventions). This fact is due to two significant factors: The first one is the amount of water used by BI, impacting the yield and consequently the total return. The second factor is the increase in water costs generated mainly by the high upfront investment cost (both equipment and installation) of SDI compared to BI investment cost. The capital cost associated with installing such a system limits adopting this technology in a short time. Therefore, in the medium and long-run periods, the sensitivity of investment and water-saving indicate that SDI installation and its use under the three interventions could be a profitable investment. Thus, using SDI at the 60% rate of water requirement, if combination equivalent to 12,841.2 kg/ha/y, is valued at $20,032.27 ha/y, coupled with 35% water savings, valued average and per year and hectare, at 74.45 $. In 10 y, the total value of net profit is estimated to be US$3,040 ha. Therefore, the water-saving will be around 744.5 $/ha. This result suggests water economic profitability in the long term by using the SDI system in date palm farming.

Table 4
Date palm productivity under the DI and SDI irrigation systems (kg/tree and kg/ha)

Irrigation intervention method	Yield – experimental irrigated area (kg/tree)	Yield – potential irrigated area (kg/ha)
INTER I: irrigation with surface drip irrigation (DI)	78.04^a (SD = 3.22)	12,800
INTER II: irrigation with surface drip irrigation (SDI)	75.00^a (SD = 2.89)	12,300

Source: Owen elaboration from experimental data from Date Palm Project Team in Kingdom of Saudi Arabia (2017).
Notes: (1) Number of date palm trees/ha (10,000 m^2) = 164;
(2) [a]Not significantly different according to LSD (0.05); SD: is the standard deviation.

4.2. Empirical research findings and discussion: Saudi Arabia

4.2.1. Economic evaluation: date palm yield

The irrigation method (DI vs. SDI) on the date palm productivity is presented in Table 4. It is worth indicating that the irrigation method (DI or SDI) had no noticeable effect on agronomic traits of date palm trees in response to water applied. The decreased water supply from 100% of crop evapotranspiration (DI) to 70% of crop evapotranspiration did not show any significant differences in yield, fruit weight, fruit length, and fruit diameter [20]. Figures displayed in Table 4 above suggest that no significant difference exists in terms of date palm productivity under the two irrigation systems (DI and SDI). The DI scenario's productivity level is about 78.04 kg/tree while it was around 75.0 kg/tree under the SDI scenario. As it is noted, the comparison of the productivity of the date palm – variety *Khalas* – between both systems suggests that a slight decrease of this productivity under the SDI system will be recorded in comparison to DI. This difference of productivity between both interventions is average for about 3.04 kg/tree and about 500 kg by hectare. At the current market price, we note a difference for about 3,750 Saudi Riyal ($1,000) at the hectare if we consider the market price of *Khalas* at 7.5 SR (US$2) the kg. This is from the difference in using these two irrigation methods. Therefore, if we want to evaluate the real return and the net profit, we must consider the water cost for each intervention in addition to the running costs in each case.

4.2.2. Environmental evaluation: water use efficiency

Results show that water productivity (kg/m^3) is about 0.96 and 1.32 kg/m^3 under DI and SDI. This finding suggests that the SDI system is more efficient in comparison with the DI system. Such results also indicate that WUE was increased by 27% more in SDI cases where WUE = 1.32 kg/m^3 compared to surface drip irrigation (DI) where WUE = 0.96 kg/m^3. These findings confirmed that SDI contributes to saving around 27% of the irrigation water without decreasing the date palm productivity level during the study period. This amount of water saved by hectare under the SDI irrigation system is estimated to be around 4,013.65 m^3. Such results indicate a potential money-saving ranging from 124.42 to 204.67 $/ha, using SDI technology, under the three different water pricing scenarios, compared to DI (Table 5).

4.2.3. Economic and financial analysis

The irrigation method will affect the total return and net profit. We should also indicate that the installation system's initial cost is higher than surface drip irrigation due to the high cost of equipment, maintenance, and installation. The hypothesis considered for the economic and financial analysis are as follows: The average cost of installing surface drip irrigation (DI) systems is estimated at US$10,500/ha. The cost of depreciation, operation, and maintenance is estimated at US$1,680/ha; The expected life of the DI and SDI systems is expected to be 10 y; The quantity of water used for one ha of *Khalas* date palm trees using surface drip irrigation (DI) system is estimated at 13,331.83 m^3/ha; The cost of this water used is around US$546.605 ha/y, considering an average price of US$0.041/m^3; The average cost of installing SDI is estimated at US$12,396.4/ha. The cost of depreciation, operation, and maintenance is estimated at US$3,585.87 ha/y; The quantity of water used for one ha of *Khalas* date palm trees using SDI is estimated at 9,318.18 m^3/ha respectively. The cost of the used amount of water is US$382.04 ha/y considering the average price of US$0.041/m^3; The economic analysis was conducted taking into consideration the depreciation of the installation irrigation system in both cases (DI and SDI); The results are at the hectare level, and all date palm trees are in full production. Empirical findings displayed in Table 6 show the effect of irrigation method on the water cost, total return, and net profit considered in average values at the hectare level. Results indicated that, under SDI, the total return, total variable costs, water costs, and net profit were 18,450; 5,400; 3,967.91; 9,082.09 $/ha, respectively.

Table 5
Volume of water consumed and saved under DI and SDI irrigation systems (m^3/ha and US$/ha)

Irrigation intervention	Water use efficiency (kg/m^3)	Total water consumed (m^3/ha)	Total water saved (m^3/ha) DI vs. SDI	Potential water saving (US$/ha) DI vs. SDI Scenario I	Potential water saving (US$/ha) DI vs. SDI Scenario II	Potential water saving (US$/ha) DI vs. SDI Scenario III
INTER I: drip irrigation (DI)	0.96	13,331.83	–	–	–	–
INTER II: surface drip irrigation (SDI)	1.32	9,318.18	4,013.65	124.42	164.56	204.67

Source: Owen elaboration from experimental data from Date Palm Project Team in Kingdom of Saudi Arabia (2017)
Notes: (1) Number of date palm trees/ha (10,000 m^2) = 164;
(2) *Water pricing scenarios:* the combined capital, maintenance, and energy cost of pumping groundwater from a typical dug well for traditional irrigation are estimated at US$0.031/m^3 (Scenario I) for average conditions. Pumping costs from a tube well for a modem irrigation system, requiring a larger pumping head, are between US$0.041 (Scenario II) and US$ 0.051/m^3 (Scenario III).

Table 6
Effect of irrigation method on total cost, total return and net profit – variety *Khalas*

Irrigation intervention	Yield (kg/ha)	Total return ($/ha)	Total variable costs ($/ha)	Water costs ($/ha)	Net profit ($/ha)
INTER I: drip irrigation (DI)	12,800	19,200	5,400	2,226.605	11,573.39
INTER II: surface drip irrigation (SDI)	12,300	18,450	5,400	3,967.91	9,082.09

Source: Owen elaboration from experimental data from Date Palm Project Team in Kingdom of Saudi Arabia (2017).
Notes: (1) The market price of the variety *Khalas* is estimated to be 7.5 SR (US$2);
(2) The total variable costs were estimated at US$5,400/ha;
(3) In the total return, we consider only 75% of the production is marketable (25% are considered as waste);
(4) water costs are calculated using the following estimation: for the two irrigation systems (DI and SDI), the irrigation/water cost by hectare includes the equipment cost (depreciation), operating, maintenance cost, and the value of the consumed amount of water.

Furthermore, by using DI, we note a significant difference in net profit when using this irrigation system. This variation is about US$2,491.305 ha. Total return and net profit increase values of *Khalas* date palm trees increased with the DI irrigation method compared to the SDI. This fact is due to two significant factors: The first one is the amount of water used by DI, which impacts the yield and, consequently, the farmer's total return. The second factor is the increase in water costs generated mainly by the high upfront investment cost of SDI compared to DI investment cost. The capital cost associated with installing such a system limits adopting this technology in a short time. Therefore, in the medium and long-run periods, the sensitivity of investment and water-saving indicate that installation of SDI could be a profitable investment in the case of the following combination of 12,300 kg/ha/y, valued at $18,450 ha/y, coupled with 27% water savings, valued, on average and per year, at $164.56, could exist as the result of such an implementation. 10 y the total value of water-saving will be around 1,650 $/ha. This result suggests water economic profitability in the long term by using the SDI system in date palm farming.

5. Concluding remarks and policy recommendations

In this research paper, BI and SDI were examined at Al-Kamil and Al-Wafi Agricultural Research Station, Oman for water use efficiency, economic performance, and yield of date palms (Cv. *Khalas*). Three intervention levels on SDI have been used: subsurface drip irrigation at the rate of 60%, 40%, and 20% of water requirement. This experimental study showed that SDI under the three intervention uses water more efficiently than the BI system. Economic findings suggest that using the SDI method has an additional cost but is economical in the long term as the SDI found to sustain the date palm farming system in this region where arid conditions act as natural constraints for expansive agriculture. These findings suggest the following recommendations:

- The investment/capital cost required to install subsurface drip irrigation is relatively high. Therefore, measures can be taken to reduce the cost of equipment by promoting the production and supply of low-cost SDI systems.
- The adoption of modern irrigation techniques is essential for the region to increase water use efficiency and date palm productivity. Therefore, in a short time, the capital cost associated with installing such a system limits the probability of adopting this technology. It is imperative to create favorable conditions so that a more significant number of farmers can benefit from such technologies. The creation of networking among different institutions related to applying this modern irrigation technology and public and private financial institutions and support services could be an example of mechanisms to enhance adoption.

The SD and SDI systems' performance was also evaluated in terms of water use efficiency, economic viability, and yield of date palms (Cv. *Khalas*) at Farm Al Briga – station of Saudi Arabia. The results of this study showed that SDI was more efficient in comparison to the DI technology. Findings indicate potential money-saving using SDI, under the tree different water pricing scenarios, compared to DI. This saving is ranging from 124.42 to 204.67 $/ha. This result suggests the existence of water economic profitability by using the SDI system in date palm farming. Based on these findings, the following recommendations are developed for the Kingdom of Saudi Arabia case study:

- Extension education programs are to be developed and implemented to enhance farmers' adoption rates of modern irrigation methods such as SDI, given its technical efficiency and economic viability.
- Further studies to be carried out to investigate the barriers to adopting this new irrigation method and developing solutions to overcome these barriers to conserve limited water resources for obtaining Saudi sustainable agriculture goals.

Acknowledgments

This work was conducted as part of the ICARDA's Arabian Peninsula Regional Program (APRP) current project, "Developing Sustainable Production Systems for Date Palm in the Gulf Cooperation Council countries". The project is funded by the Gulf Cooperation Council (GCC) Secretariat (https://www.gcc-sg.org/en-us/Pages/default.aspx) under a grant agreement with the International Center for Agricultural Research in the Dry

Areas (ICARDA – https://www.icarda.org/). The authors also would like to thank the hard work and dedication of the national project partners in the Ministry of Agriculture, Fisheries and Water Resource, Sultanate of Oman, and the Ministry of Environment, Water and Agriculture, in Kingdom of Saudi Arabia.

References

[1] R. Al-Yahyai, M. Mumtaz Khan, Date Palm and Perspective in Oman, J.M. Al-Khayri, S.M. Jain, D.V. Johnson, Eds., Date Palm Genetic Resources and Utilization, Vol. 2, Springer, Dordrecht, Heidelberg, New York, London, 2015, pp. 207–240.

[2] M.O. El Mardi, S.B. Salama, E.C. Consolacion, M.S. Al-Shabibi, Effect of treated sewage water on vegetative and reproductive growth of date palm, Commun. Soil Sci. Plant Anal., 26 (1995) 1895–1904.

[3] M.O. El Mardi, S.B. Salama, E.C. Consolacion, M. Al-Solomi, Effect of treated sewage water on the concentration of certain nutrient elements in date palm leaves and fruits, Commun. Soil Sci. Plant Anal., 29 (1998) 763–776.

[4] R. Al-Yahyai, L. Al-Kharusi, Sub-optimal irrigation affects chemical quality attributes of dates during fruit development, Afr. J. Agric. Res., 7 (2012b) 1498–1503.

[5] K.N. Tiwari, P.K. Mal, R.M. Singh, A. Chattopadhyay, Response of Okra (*Abelmoschus esculentus* (L.) Moench.) to drip irrigation under mulch and non-mulch condition, Agric. Water Manage., 38 (1998) 91–102.

[6] T.L. Thompson, T.A. Doerge, R.E. Godin, Subsurface drip irrigation and fertigation of broccoli: II. Agronomic, economic, and environmental outcomes, Soil Sci. Soc. Am. J., 66 (2002) 178–185.

[7] T.L. Thompson, S.A. White, J. Walworth, G.J. Sower, Fertigation frequency for subsurface drip-irrigated broccoli, Soil Sci. Soc. Am. J., 67 (2003) 910–918.

[8] B. Hanson, D. May, The effect of drip line placement on yield and quality of drip-irrigated processing tomatoes, Irrig. Drain. Syst., 21 (2007) 109–118.

[9] B. Safi, M.R. Neyshabouri, A.H. Nazemi, S. Massiha, S.M. Mirlatifi, Water application uniformity of a subsurface drip irrigation system at various operating pressures and tape lengths, Turk. J. Agric. For., 31 (2007) 275–285.

[10] ASAE Std. Soil and Water Terminology, S 526.1. ASAE Standards, American Society of Agricultural Engineers, St. Joseph M.I., 1999.

[11] A.I. Al-Amoud, M.A. Bacha, A.M. Al-Darby, Seasonal water use of date palms in the Central Region of Saudi Arabia, Agric. Eng. J., 9 (2000) 51–62.

[12] R. Bourziza, A. Hammani, M. Kuper, A. Bouaziz, Water saving in arid regions: comparison of innovative techniques for irrigation of young date palms, World Acad. Sci. Eng. Technol., Int. J. Environ. Ecol. Eng., 8 (2014) 771–776.

[13] D.K. Singh, T.B.S. Rajput, Response of lateral placement depths of subsurface drip irrigation on okra (*Abelmoschus esculentus*), Int. J. Plant Prod., 1 (2007) 73–84.

[14] J.E. Ayers, C.J. Phene, R.A. Schoneman, B. Meso, F. Dale, J. Penland, Impact of Bed Location on the Operation of Subsurface Drip Irrigation Systems, Proc. 5th Int. Microirrigation Congress, ASAE, 1995, pp. 168–174.

[15] K.N. Tiwari, P.K. Mal, R.M. Singh, A. Chattopadhyay, Response of Okra (*Abelmoschus esculentus* (L.) Moench.) to drip irrigation under mulch and non-mulch conditions, Agric. Water Manage., 38 (1998) 91–102.

[16] B. Douh, A. Boujelben, Water saving and eggplant response to subsurface drip irrigation, J. Agric. Segment, 1 (2010a) 1–12.

[17] J. Payero, Is Subsurface Drip Irrigation Right for Your Operations? Crop Watch New Service Web Page, Univ. of Nebraska, Institute of Agriculture and Natural Resources Cooperative Extension, 2002.

[18] B. Dhehibi, M. Ben Salah, A. Frija, A. Aw-Hassan, H. Al Wahaibi, Y. Al Raissi, A.Z. Dewidar, A.Z.Y. Al Fehaid, M. Al-Marri, M. Al-Yafei, H. Al-Asmakh, A.F. Al-Kuhais, Economic and Environmental Evaluation of Different Irrigation Systems for Date Palm Production in the GCC Countries, Technical Report, International Center for Agricultural Research in the Dry Areas – ICARDA, 2018, 52p.

[19] T.A. Howell, Enhancing water use efficiency in irrigated agriculture, Agron. J., 93 (2001) 281–289.

[20] A.Z. Dewidar, M. Ben-Salah, Water saving in arid regions: a comparison of surface and subsurface drip irrigation systems for irrigation of date palms, Am. J. Innovative Res. Appl. Sci., 2 (2016) 289–296.