WATER SAVING IN ARID REGIONS: A COMPARISON OF SURFACE AND SUBSURFACE DRIP IRRIGATION SYSTEMS FOR IRRIGATION OF DATE PALMS

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ABSTRACT
Surface and subsurface drip irrigation methods can play a significant role in overcoming the scarcity of water mostly in water shortage areas. A field study was conducted to investigate the effectiveness of surface and subsurface drip irrigation systems, in terms of both water use requirement and yield of date palms at Al-Hassa, Saudi Arabia. Mature palm trees of Khalas variety with 8 m spacing for both row to row and tree to tree were selected. Irrigation scheduling was done through evapotranspiration (ET)-based sensors as well as crop water requirement guidelines for Kingdom of Saudi Arabia to ensure enough soil water levels in the soil. Statistical testing indicated that methods of irrigation had not noticeable effect on agronomic traits of date palm trees in response to water applied, where decreasing water supply from 100% of crop evapotranspiration (surface drip) to 70% of crop evapotranspiration (subsurface drip) did not show any significant differences in yield, fruit weight, fruit length and fruit diameter. The water use efficiency was significantly increased by 27% more in case of subsurface drip (1.32 kg m^{-3}) compared to surface drip irrigation system (0.96 kg m^{-3}). Subsurface drip irrigation system was additionally found to be the favorable in respect of economic analysis to save 30% of the applied irrigation water at the time in which produced almost the same net profit.
Keywords: Surface drip irrigation, subsurface drip irrigation, water conservation, arid areas, date palms

INTRODUCTION

Increasing the water supply in Saudi Arabia is questionable. Policy to achieve water security and food security is to increase the water use efficiency and water productivity producing more with less water in all water sectorial uses particularly the agriculture sector in which receiving nearly 85% of the available water resources. Technically, several approaches are now implemented for better water saving in the irrigated agriculture among them the introduction of the new irrigation techniques such as surface and subsurface drip irrigation systems.

Date palm represents roughly 74% of the total cultivated area under fruits in the entire Kingdom (Kassem, 2007). Date palm trees are usually irrigated by the flood irrigation system that uses an abundant amount of water. However, amount of the water applied to the farms by farmers are usually based on their experience (Al-Amoud, 2010). Applications of traditional irrigation methods such as flood irrigation are not only putting further stress on the already dwindling water resources but they also happen to be wasteful (Faures et al., 2001; Darfaoui and Al-Assiri, 2010). Adoption of modern irrigation techniques is needed to be emphasized to increase water use efficiency. Drip irrigation and subsurface drip irrigation systems are the most effective ways to convey directly water and nutrients to plants and not only save water but also increase yield of crops

On one hand, a comparison of the water use efficiency between different irrigation methods of date palm (drip, flooding and micro-jet) showed that drip irrigation system is the most efficient, followed by flood irrigation system and micro-jet (Al-Amoud et al., 2000). On the other hand, subsurface drip irrigation represents the recent improvement of irrigation, because it prevents, or in most cases, significantly reduces losses of direct evaporation, runoff and deep percolation (Hanson and May, 2007; Safi et al., 2007). Thus, subsurface drip irrigation is considered as the most effective way to provide water and nutrients directly to the plants and to increase productivity of crops (Tiwari et al., 1998; Thompson et al., 2002; Thompson et al., 2003; Douh and Boujelben, 2010).

Camp, (1998) reviewed the results of some previous works that compared the crop yield both in subsurface and other different methods of surface irrigation. He concluded that crop yields for subsurface drip systems were equal to or better than the other systems in all cases, including different crops, soils, and cropping conditions. Barth, (1995) compared the subsurface drip irrigation system with traditional surface drip system and sprinkler irrigation system, results have shown that the overall water use is reduced by 50% compared to sprinkler system and 30% compared to traditional surface drip irrigation system. Hassanli et al. (2009)

compared three irrigation methods, drip, subsurface drip and furrow irrigation. Results showed that the maximum amount of water with highest use efficiency was obtained from subsurface irrigation system.

Selim et al. (2009) found that subsurface drip irrigation system was more efficient than surface drip irrigation system on improving potato tubers yield quantity, quality parameters and nutrients concentration content. Al-Omran et al. (2010) concluded that the subsurface drip irrigation not only increased the yield and water use efficiency of the tomato crop but also saved the amount of applied water by creating a good moisture distribution in the root zone depth.

Economical analysis studies have shown the superiority of the subsurface drip irrigation over center pivot sprinkler irrigation system. It was found that the total cost for the subsurface drip irrigation system per hectare (including; investment management, operation , etc..) is less by 30% compared to the center pivot system (Dhuyvetter et al., 1994). The aim of this research work is to investigate the efficiency and practicality of subsurface drip system for irrigating date palm trees and to compare it with surface drip irrigation system, especially in areas where water is a limited source.

MATERIAL AND METHOD

Location and site characteristics

This study was conducted at the experimental station at the Centre for Date Palm and Dates, Al Hassa, Kingdom of Saudi Arabia (Fig.1). The geographical location coordinates of the farm are 25° 22'N latitude, 49° 34'E longitude and 179 m above the sea level. The soil profile of the experimental site in the upper 0–90 cm soil was sandy loam texture composing of 50 % sand, 24% silt and 26% clay. The average soil water content at field capacity from surface soil layer down to 90 cm depth at 30 cm intervals was 15.5 %, and the permanent wilting point for the corresponding depths was 6%, respectively (Table 1).

Figure 1. Localization of the field experiment

Table1. Physical and chemical properties of the filed at different soil layers

Soil depth (cm)	Particle size distribution (%)			pH	PWP (%)	FC (%)	ECe (dS m^{-1})
	Sand%	Silt%	Clay%				
0-30	61	16	23	7.81	5.32	14.74	1.59
30-60	45	26	29	7.83	6.54	15.90	2.19
60-90	45	30	25	7.75	6.00	16.00	1.83

PWP = Permanent Welting Point, FC = Field Capacity, ECe = Electrical Conductivity of Saturated Paste Extract.

Climatic conditions

The research field is situated in arid climatic region. The averages of air temperature, relative humidity, wind speed, sunshine duration and total precipitation were monitored by an in-situ meteorological station (Davis vantage pro2). The air water vapor pressure deficit was calculated using daily and hourly average temperatures and relative humidity. Finally, the reference evapotranspiration (ETo, mm day^{-1}) was calculated according to the Penman-Montieth equation (Allen et al., 1998):

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma[(900U_2)/(T + 273)](e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where R_n and G are daily net radiation and soil heat flux in MJ m^{-2}, respectively, Δ is the slope of saturation vapor pressure curve (kPa/ ºC), U_2 is the average daily wind speed at 2 m above soil surface (m s^{-1}), γ is the moisture constant (kPa/ ºC), T is the average daily air temperature at 2 meter height (ºC) and (es - ea) is the saturated vapor pressure deficit (kPa).

Cropping details and measurements

Field measurements were taken during the productive cycle of 15 years old date palm trees. 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 average number of 55 leaves per palm. The date palms were spaced at 8.0 m for both row to row and tree to tree. The chemicals and pesticides were applied identically as necessary to all trees. Fertilizers were divided and delivered in accordance with farm management practice for palm trees. Date palm yields, physical parameters and soil water data were determined for both surface ad subsurface drip systems.

Irrigation system description

The date palm trees were separately irrigated with surface drip irrigation (DI) and subsurface drip irrigation (SDI) during the study period. The irrigation system consisted of head unit, main and sub-main delivery polyethylene pipes of 75 and 63 mm in diameter, respectively (Fig.2). The main line was connected to 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 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 system was checked for leakage prior to back filling.

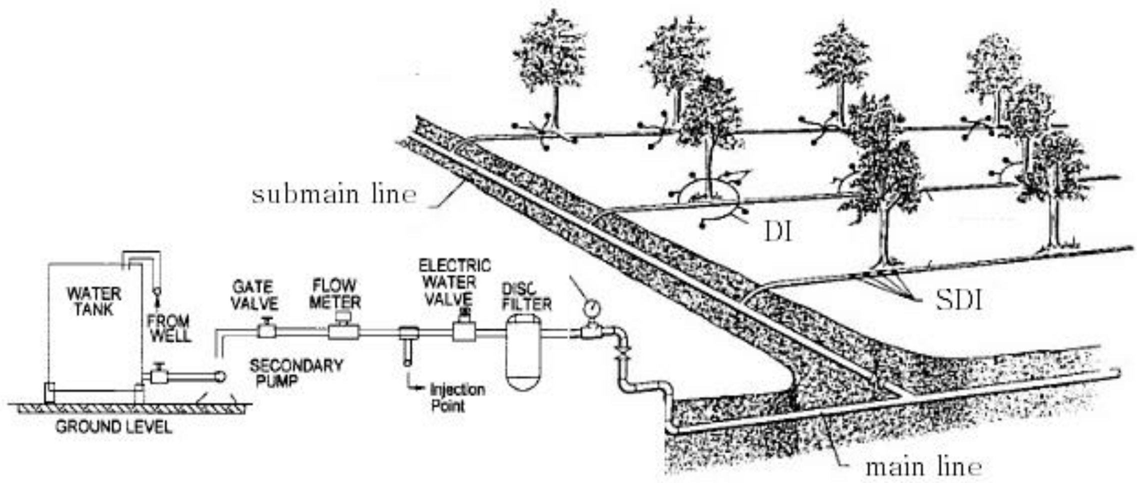

Figure 2. Schematic of the main water supply and irrigation system components

Irrigation scheduling

The date palm trees were daily irrigated with a water volume (V_w) according to the actual climatic data acquired from a nearby-automated weather station (Eqs. 2 and 3). The amounts of water were measured at each irrigation event by multi jet dry type water meters, which were fixed to the sub main lines.

$$V_w = \frac{ET_o \times K_c \times A_p \times K_r}{E_i \times (1 - LR)} \text{...........for(DI)} \quad (2)$$

$$V_w = \frac{70}{100} \times \left[\frac{ET_o \times K_c \times A_p \times K_r}{E_i \times (1 - LR)} \right] \text{...........for(SDI)} \quad (3)$$

where ET_o is the reference evapotranspiration, Kc is the constant crop coefficient, Ap is the soil surface area, E_i is the irrigation system efficiency, LR is the leaching requirements, K_r is a reduction factor, DI is the drip irrigation and SDI is the subsurface drip irrigation.

The reduction factor (K_r) was estimated using equation (4) as suggested by Keller and Bliesner (1990):

$$K_r = 0.1 \times GC^{0.5} \quad (4)$$

where K_r is reduction factor and GC is ground cover value

The ground cover as percentage was calculated by the procedure described by Hellman (2004) as follows:

$$GC(\%) = \frac{\text{Shaded area per tree}}{\text{Area per tree}} \times 100 \quad (5)$$

where GC is the ground cover (%), Shaded area per tree = tree spacing within row x average width of measured shaded area between two trees, and Area per tree = row width x tree spacing within row.

Leaching requirements (LR) were calculated by the equation (6) suggested by Frere and Pruitt (1979):

$$LR = \frac{EC_W}{2 \max . EC_e} \cdot \frac{1}{LE} \quad (6)$$

where EC_w is the electrical conductivity of water (mmho/cm), EC_e is the electrical conductivity of soil extract (mmho/cm), max EC_e is the maximum electrical conductivity of soil extract tolerated by date palms (mmho/cm) and LE is the leaching efficiency (90% for sandy and loamy sands).

Water use efficiency
Water use efficiency was calculated using equation (7) as suggested by Howell, 2001.

$$WUE = \frac{y}{w} \quad (7)$$

where WUE is water use efficiency (kg/m^3), y is total marketable date palm yield (kg) and w is seasonal irrigation applied water (m^3)

Economic analysis
Economic analysis was conducted according to Worth and Xin (1983) in which total costs of date palm yield, water price and running costs were included.

Statistical analysis:
The results were examined statistically by using the analysis of variance (ANOVA) procedure from the statistical analysis system (SPSS 21 Statistical Package). Fisher's protected least significant difference (LSD) was used to compare treatment means for significant ($p \leq 0.05$) effects.

RESULT AND DISCUSSION

Weather conditions in the experimental site
Figure 3 summarizes the main climatic data of the study area during the research period. The data revealed that the maximum mean monthly temperature was 33.30 ºC during the summer months (June to September), while the lowest mean monthly temperature was 17.49 ºC during the winter months (December to February). The highest mean relative humidity was 50.72 % during winter months, while the lowest mean relative humidity was 33.86 % during summer months. Rainfall was very scarce, which is usual in the area. The maximum monthly rainfalls were 0.79 and 0.83 mm in March and November, respectively. The wind speed fluctuated during the observational period with an average value of 1.27 km/hr over the entire experimental period. The maximum mean daily value of net radiation was 22.89 MJ/m^{2}day in May.

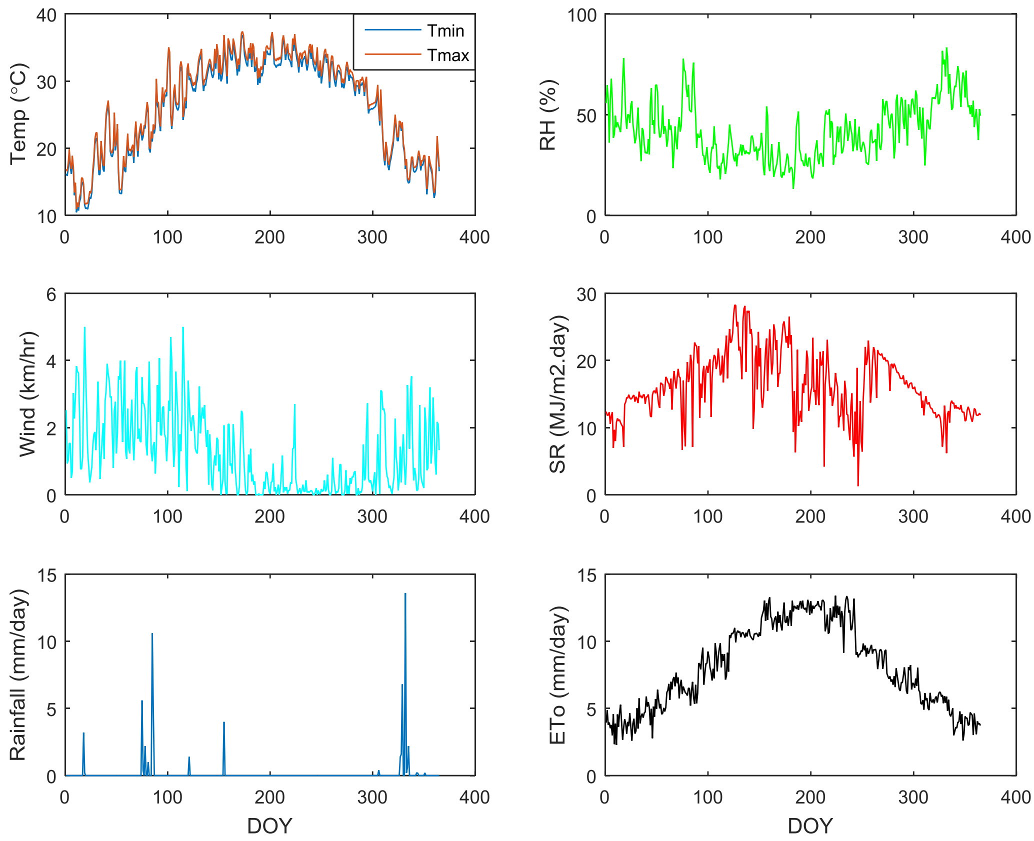

Figure 3. Average daily values of climatic conditions in the experimental site

Amount of the applied water

The quantity of water applied varied with the time period, depending on the atmospheric temperature and other climatic parameters. Figures 4 and 5 show how the quantity of water applied in mm per month fluctuated between January to December (2015). It is clear from these figures that minimum and maximum monthly values of irrigation depth added in initial growth stage through drip irrigation (DI) and subsurface drip irrigation (SDI) were 91, 185 and 64, 129 mm, respectively. With increasing temperatures from April, date palm trees looked more stressed requiring more frequent irrigations. During summer months (May to July), the amount of water applied to DI and SDI increased and ranged between 292 and 204 mm/month, respectively. In flowering and fruiting stages, the amount of water applied to DI and SDI decreased and fell to 115 and 81 mm, respectively.

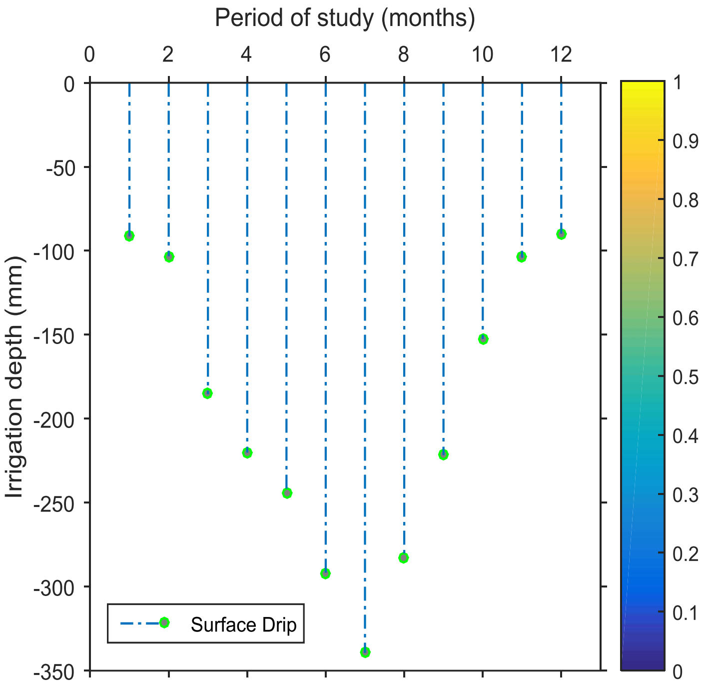

Figure 4. Amount of irrigation water applied to surface drip plots

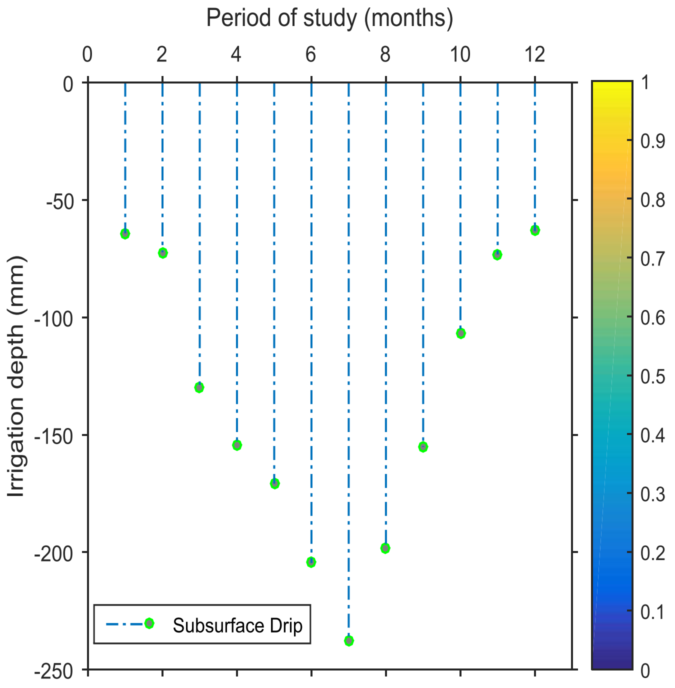

Figure 5. Amount of irrigation water applied to subsurface drip plots

Subsurface drip versus drip irrigation method

Irrigation water was applied to all sub-areas as per irrigation scheduling (Fig. 6). It can be seen in figure 6 that the quantity of water applied to drip irrigation(DI) and subsurface drip irrigation (SDI) for the same period was close in both initial and late season stages of the crop, and get considerable differences in development and mid-stages. The curves showed also that the amount of water applied to SDI was 30 % less than the quantity of water applied to DI, where the average monthly water depth applied to DI was 194 mm compared to SDI (136 mm) which is a difference of 58 mm. This is mainly because SDI prevents, or in most cases, significantly reduces losses of direct evaporation, runoff and deep percolation. These results were similar to findings reported by (Selim et al., 2009; Hanson and May, 2007; Safi et al., 2007).

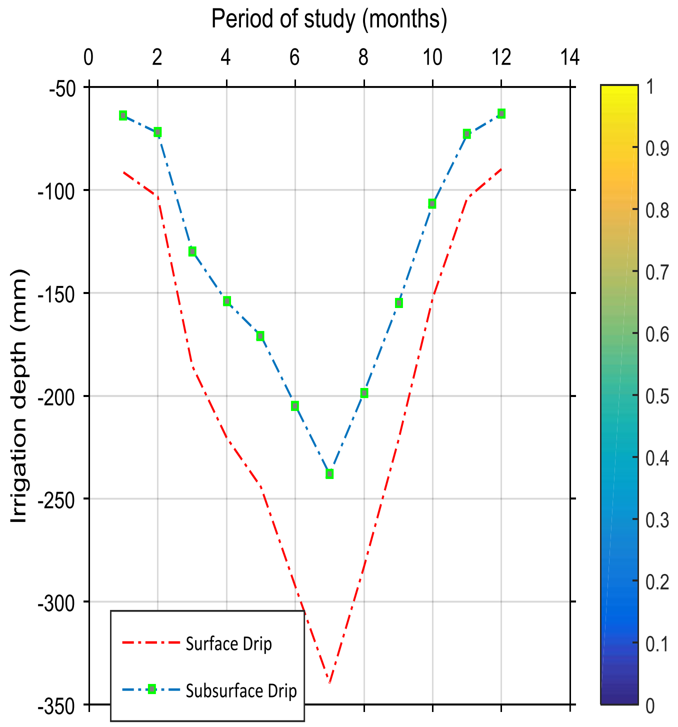

Figure 6. Amount of irrigation water applied under DI and SDI systems

Date palm yield and physical analysis

Method of irrigation had not noticeable effect on agronomic traits of date palm trees in response to water applied, where decreasing water supply from 100% of crop evapotranspiration (surface drip) to 70 % of crop evapotranspiration (subsurface drip) did not show any significant differences in yield, fruit weight, fruit length and fruit diameter (Table 2). In details, results of analysis indicated that values of yield, fruit weight and fruit diameter under drip irrigation (DI) were a little bit higher than the corresponding values under subsurface drip (SDI) method. This may be due to fact that water applied at 100% of crop evapotranspiration adequately meets the crop water requirement. On contrast, the fruit length confirmed the priority of SDI as compared to DI method. This result is in agreement with the findings of Camp (1998), Smajstrla and Locascio (2000) and Vories et al. (2009).

Table 2. Effect of irrigation method on agronomic traits of date palm trees

Irrigation method	Yield (ton/ha) ±SD	Fruit weight (gram) ±SD	Fruit length (mm) ±SD	Fruit diameter (mm) ±SD
Surface Drip	12.8±3.22[a]	8.4±0.74[b]	33.94±2.55[c]	20.57±1.74[d]
Subsurface Drip	12.3±2.89[a]	8.26±1.15[b]	34.44±2.01[c]	19.57±1.49[d]

Means with the same class followed by the same letter are not significantly different according to LSD (0.05), and SD is the standard deviation.

Water use efficiency

A comparison of water use efficiency (WUE) between both irrigation methods (drip irrigation, DI and subsurface drip irrigation, SDI) of date palm showed that SDI system is the most efficient (Fig. 7). Data shown in figure 7 cleared that WUE was significantly increased by 27% more in case of SDI (1.32 kg m^{-3}) compared to DI (0.96 kg m^{-3}). This confirmed that SDI produced not only same date palm yield, but also saved the irrigation water during the study period. These results were consistent with (Al-Omran et al., 2010; Hassanli et al., 2009; Singh and Rajput, 2007).

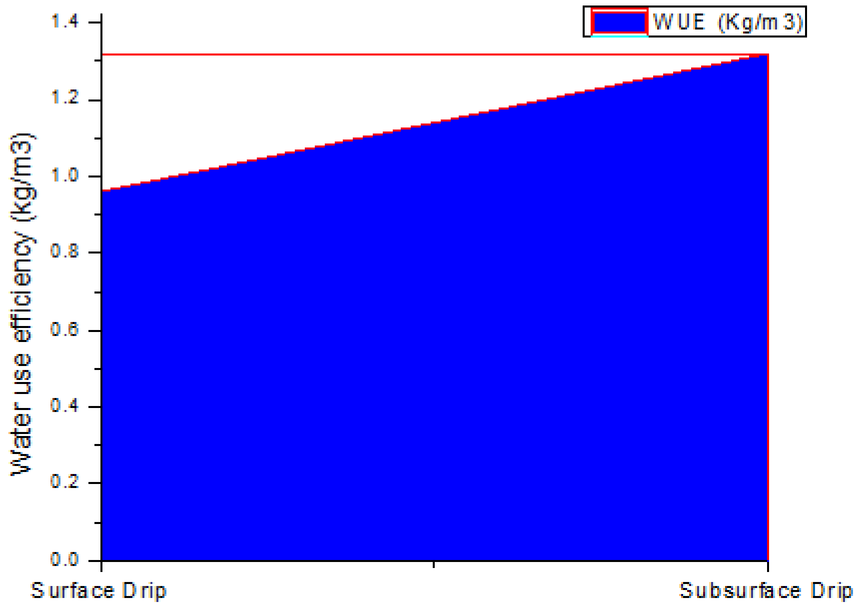

Figure 7. Water use efficiency under surface and subsurface drip systems

Economic analysis

The total return and net profit of date palm were slightly affected by drip irrigation (DI) and subsurface drip (SDI) treatments (Table 3). In details, the average values of water cost, total return and net profit were 704, 10206 and 6979 $ ha^{-1} for DI and 493, 9833 and 6817 $ ha^{-1} for SDI. It is clear that total return and net profit values of date palm trees were slightly increased with increasing the amount of irrigation water (DI), where the date palm plants gave almost the same yield in both irrigation methods.

Table 3. Effect of irrigation method on total cost, total return and net profit.

Irrigation method	Water cost ($/ha)	Running costs ($/ha)	Total return ($/ha)	Net profit ($/ha)
Surface Drip	704	2523	10206	6979
Subsurface Drip	493	2523	9833	6817

CONCLUSIONS

This study examined the performance of a surface and subsurface irrigation systems, in terms of both water use requirement and yield of date palms. The results of the field experiment showed that the subsurface drip irrigation uses water more efficient compared to the surface drip system in oasis areas, where a considerable amount of water lost through evaporation was potentially saved. Furthermore, subsurface drip irrigation system was found to sustain good date palms agronomic parameters in comparison with the drip irrigation scheduling method when it is designed, maintained and used properly.

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