Original Research Article

Estimation of water requirements by several methods and impact of deficit irrigation on the date palm productivity and water use efficiency

ABSTRACT

This study was conducted on (Khalas) date palm, which is well-known for its cultivation in the regions of the Kingdom of Saudi Arabia (KSA) to estimate the monthly, annual irrigation water requirements and effect of different deficit irrigation levels on yield, soil moisture distribution and water use efficiency. The experiment consisted of four levels of deficit irrigation: 60%, 80%, 100% and 120% of crop evapotranspiration (ETc) compared with traditional irrigation. Two different water qualities: well 4.79 dS/m and treated electrical conductivity 1.86 dS/m. Several methods of estimating water requirements were used, such as the Penman Monteith method, the evaporation pan, and the water balance. The results indicated that the traditional irrigation (farm method) gave the highest amount of productivity with the most water consumption. The results showed that the water requirements of the Khalas date at the 100% of crop evapotranspiration (ET_c) were 53.57, 37.67, 58.89 m^3/year/tree, calculated using water balance, the evaporation pan and Penman Monteith equations, respectively. The results indicated that an increase in the amount of well water added by the traditional irrigation compared to the deficit irrigation, whereas the increase % at 100% ETc ranged from 38.71% to 195.59% using well water, while the increase % ranged from 22.63% to 280.37 % in March and November, respectively. While in the case of comparing the quantities of water added by the traditional method with 60% ETc of the water requirements, the increase% ranged from 78.71% to 235.59% in the case of well water and 62.63% to 320.37% using treated water of March and November months, respectively.

Keywords: Deficit irrigation, water requirements, water use efficiency, date palm.

1. INTRODUCTION

The Kingdom of Saudi Arabia (KSA) is located within the arid and semi-arid regions of the world, and most of the soils of the Kingdom are considered sandy coarse soils with a high percentage of calcium carbonate, decrease in soil organic matter and low fertility, and also low water holding capacity due to high rates of infiltration [1, 2]. Therefore, the water use efficiency (WUE) is low, so it is important to add soil conditioners to rationalize water consumption in agriculture by using some natural, industrial and organic materials to improving the physical and chemical properties of soil such as texture, construction, bulk density and cationic exchange capacity (CEC), which leads to an increase in the ability of the soil to facilitate nutrients and water retention, as well as to raise soil fertility and thus increase productivity and protect the soil from deterioration [3].

According to the statistics of the FAO for the year 2017, the contribution of irrigated soils to food production in the world has decreased from 40% to 28%, and this indicates the paramount importance of water use efficiency, so the lack of water resources creates difficulties in cultivating land and growing crops, and these difficulties lie In the loss of large amounts of water as a result of evaporation as a result of the lack of the soil's ability to retain water, and this causes tensile drought and an increase in the rates of soil degradation and results in vast areas of desertification [4, 5]. There has been a significant change in global agricultural production in the last two decades of the past few years due to scientific, economic and technological innovations that have led to an improvement in living standards as the world's population increases and the demand for food has increased. The KSA is contribute about 17% of the total global production of dates, making it the second in the world in the production of dates, and the various regions of the KSA produce 1,539,755 tons annually. The number of date palms in the KSA is 31,234,155 on an area of 107 thousand hectares, with more than 123 thousand agricultural holdings of palm trees [6, 7, 9].
According to [7], the water requirement is 25,992 billion m^3/year, detailed to municipal uses of 3.392 billion m^3/ year (13%), industrial uses 1.4 billion m^3/year (5%), agricultural uses including non-renewable, renewable and renewable resources are 21.2 billion m^3/ year (82%). Al-Omran et al., 2018 [1] reported that the water resources in the KSA is limited in their quantities and sources due to the absence of sources of fresh surface water (rivers, lakes). Also, the amounts of rain falling on the KSA do not meet the requirements of agriculture or municipal uses [9].
Deficit irrigation is an optimization method in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle [11,12].
Thus, the aim of this study was to estimate the water requirements of the date palm using different water methods and for two sources of water quality (well and treated water) and to know the effect of different deficit irrigation on date palm productivity, water use efficiency and soil moisture distribution.

2. MATERIAL AND METHODS

2.1 Experimental Site And Soil Samples

Field experiments were conducted at college of agriculture and food sciences farm (latitude 18.9'25 24◦N and longitude 25.7'3946◦E), Riyadh, Saudi Arabia. The physical properties of soil samples collected from experimental site are shown in (Table 1).

Table 1. Physical properties of the soil and water at the experimental site

Soil depth (cm)	Bulk density (g/cm^3)	Field capacity (%)	Hydraulic conductivity (cm/day)	Texture
0–20	1.60	15.2	101.9	Loamy
20–40	1.61	15.1	101.8	Loamy sand
40–60	1.62	14.9	390.1	sand

2.2 Weather Data

Weather data, including maximum and minimum air temperature, rainfall, air relative humidity, wind speed, and direction at 2 m above ground, were measured by an automatic weather station managed by the general authority for meteorology and environmental protection in Riyadh region (KSA). The data were used to estimate the daily reference for evapotranspiration (ETc) using the modified Penman–Monteith equation according to Allen et al. 1998 [13].

2.3 Irrigation Treatments

Two sources of water quality are used for irrigation: well, and dual-treated water with an electrical conductivity of 4.79 and 1.86 dS m^{-1}, respectively. Khalas date palm trees were used and the experiment with five deficit irrigation with three replications. Deficit irrigation consisted of four levels of ETc (60%, 80%, 100% and 120%) and compared with traditional irrigation (Farm practice). Soil samples were taken from the non-farm field and irrigated with well water and treated water separately, and the three sites are spatially connected, in addition to the water used on the farm, water and soil samples were collected for three (first, middle and end of the season) with three replicates for each treatment, and the water samples were kept in plastic bottles inside the cooler at a temperature of (4°C). Moisture sensors were installed at four depths (0–50), (50–100), (100–150) and (150–200) cm, respectively. Surface and subsurface samples of soil were collected from the previously mentioned depths, and then dried, crushed and sieved using a 2 mm sieve, then physical and chemical analyzes were performed. The measurement was carried out using moisture sensors type (EM50 Data Logger, ECH2O Utility software), where the values were corrected for depths according to the method of Loki et al., 2019 [14] and the values were statistically evaluated by a number of statistical equations.

2.4 Measurements

Water requirements were calculated using the following equations:
Water balance method using Phogat et al., 2017 [15]:

$$\mathrm{ET} = \mathrm{P} + \mathrm{I} - \mathrm{D} \pm \Delta\mathrm{w} \qquad (1)$$

Where
ET is evapotranspiration, P=precipitation (mm/day); I= irrigation (mm/day); D= drainage (mm/day) and ΔW is change in soil moisture content during a certain period of time (the period between two irrigations).
Evaporation pan using Cuenca, 1989 [16] equation:

$$ET_O = K_p E_P \qquad (2)$$

Where ET_0 is the reference evapotranspiration (mm/day); *kp* = Evaporation coefficient and *Ep* = evaporation (mm/day).
The Penman-Monteith equation using Allen et al, 1998 [13] equation:

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where:
ETo= reference evaporation (mm/day); Rn = net solar radiation at the crop surface (MJ/m2/day); G= = soil heat flux intensity (MJ/m2/day); U2 = wind speed at a height of 2 m (m/s); ea = actual vapor pressure (kPa); es- ea = decrease in saturated vapor pressure (kPa); es = saturated vapor pressure (kPa); T = average daily air temperature at a height of

2 m (C^o) and Δ = slope of the curve of the relationship between saturated vapor pressure and temperature (kPa/m°).

2.5 Statistical Analysis

Statistical analysis was performed using analysis of variance method and means of treatment.

3. RESULTS AND DISCUSSION

3.1 Water Requirement

As shown in (Tables 2a,2b and 2c4), the total amounts of irrigation water calculated by different methods.

Table (2a). Average water requirements calculated on the basis of the water balance method

Months	Water requirements (m^3)			
	60%	80%	100%	120%
Jan.	1.20	1.60	1.95	2.45
Feb.	1.68	2.13	2.84	3.40
March	1.88	2.38	3.25	4.01
Apr.	2.51	3.18	4.17	5.12
May	3.22	4.05	5.29	6.57
June	3.57	4.94	6.24	7.60
July	4.36	4.95	7.26	8.82
Aug.	4.33	5.80	7.21	8.76
Sep.	3.10	4.52	5.60	6.83
Oct.	2.82	3.48	4.67	5.71
Nov.	1.78	2.19	2.95	3.65
Dec.	1.30	1.75	2.14	2.68
Total (m^3/tree)	31.76	40.97	53.57	65.60
Total (m^3/ha)	4572.80	5899.52	7714.15	9447.06

The average water requirements of a palm tree at 100% of crop evapotranspiration (Etc) calculated by the water balance method amounted to 53.57 m3/ tree/ year, with a total of

7714.15 m^3/ha/year. Also, the amount of well water calculated by the water balance method increased compared to the treated water, due to the difference in the amount of water added for the washing needs (Table 2a). Moreover, the amount of water added in the treatment of the farm (the control) calculated from the readings of the water meters, was greater than that used in the deficit irrigation experiments. In addition, the quantities added in that treatment were not accurate, whether for irrigation with well and treated water.
The water requirements of the Khalas at 100% Etc for well water quality was 37.67 m^3/tree/year, and the annual total of 5426.50 m^3/ha/year. The water requirements for the well water was equal to the same with treated water calculated by the evaporation pan (Table 2b).
The total water requirements of palm trees for the well water site was 58.89 m^3/tree/year, and annual total was 8480.80 m^3/ha/year 100% Etc (Table 2c). Alkhasha, et al., 2013 and Al-Omran, et al., 2019 [17, 18] reported that to the water requirements of date palms in the eastern region (KSA) ranged between 137 and 55 m3/tree/year and in the central region (KSA) was 195 and 78 m^3/ tree/year. The variation in the quantities of water calculated for the water requirements of the crop differed according to the water quality, difference in the amount of water required for the leaching requirements [19-21].

Table (2b).Average water requirements calculated on the basis of the evaporation pan

Months	Water requirements (m^3)			
	60%	80%	100%	120%
Jan.	0.90	1.20	1.50	1.80
Feb.	1.22	1.62	2.03	2.43
March	1.42	1.89	2.36	2.84
Apr.	1.79	2.38	2.98	3.58
May	2.27	3.03	3.79	4.55
June	2.62	3.49	4.36	5.23
July	2.76	3.68	4.60	5.53
Aug.	3.00	4.00	5.00	6.00
Sep.	2.36	3.15	3.93	4.72
Oct.	1.99	2.65	3.31	3.93
Nov.	1.30	1.73	2.17	2.60
Dec.	0.98	1.30	1.63	1.95

Total (m³/tree)	22.60	30.14	37.67	45.20
Total (m³/ha)	3254.69	4339.59	5424.49	6509.38

Table (2c).Average water requirements calculated on the basis of the Penman-Monteith equation

Months	Water requirements (m³)			
	60%	80%	100%	120%
Jan.	0.76	1.02	1.27	1.53
Feb.	1.25	1.67	2.08	2.50
March	1.94	2.59	3.24	3.89
Apr.	2.74	3.65	4.57	5.48
May	3.88	5.18	6.47	7.77
June	4.46	5.95	7.44	8.89
July	5.60	7.46	9.33	11.20
Aug.	5.52	7.36	9.20	11.04
Sep.	3.68	4.90	6.13	7.35
Oct.	2.92	3.90	4.87	5.84
Nov.	1.66	2.21	2.77	3.32
Dec.	0.92	1.22	1.53	1.84
Total (m³/tree)	35.34	47.12	58.89	70.67
Total (m³/ha)	5088.48	6784.64	8480.80	10176.96

Figure (1) shows a comparison between the amounts of water added on traditional irrigation (farm) and the deceit irrigation at 60%, 80%, 100% and 120% ETc using well water. The results showed that, the total amounts of water increased by 100% to up to 195.59%, while, the percentage ranged from 22.63% to 280.37% using treated water quality in March and November, respectively. While in the case of comparing the quantities of water added by the traditional irrigation (farm) and the deceit irrigation at 60% ETc, the percentage of increase ranged from 78.71% to 235.59% in the case of well water and 62.63% to 320.37% using treated water March and November, respectively. This results indicated that large quantities of water are lost in the case of applying the traditional irrigation compared with deficit irrigation. These results are in agreement with those reported by Czarnomski et al., 2005 [22]; Kheir et al., 2021 [23].

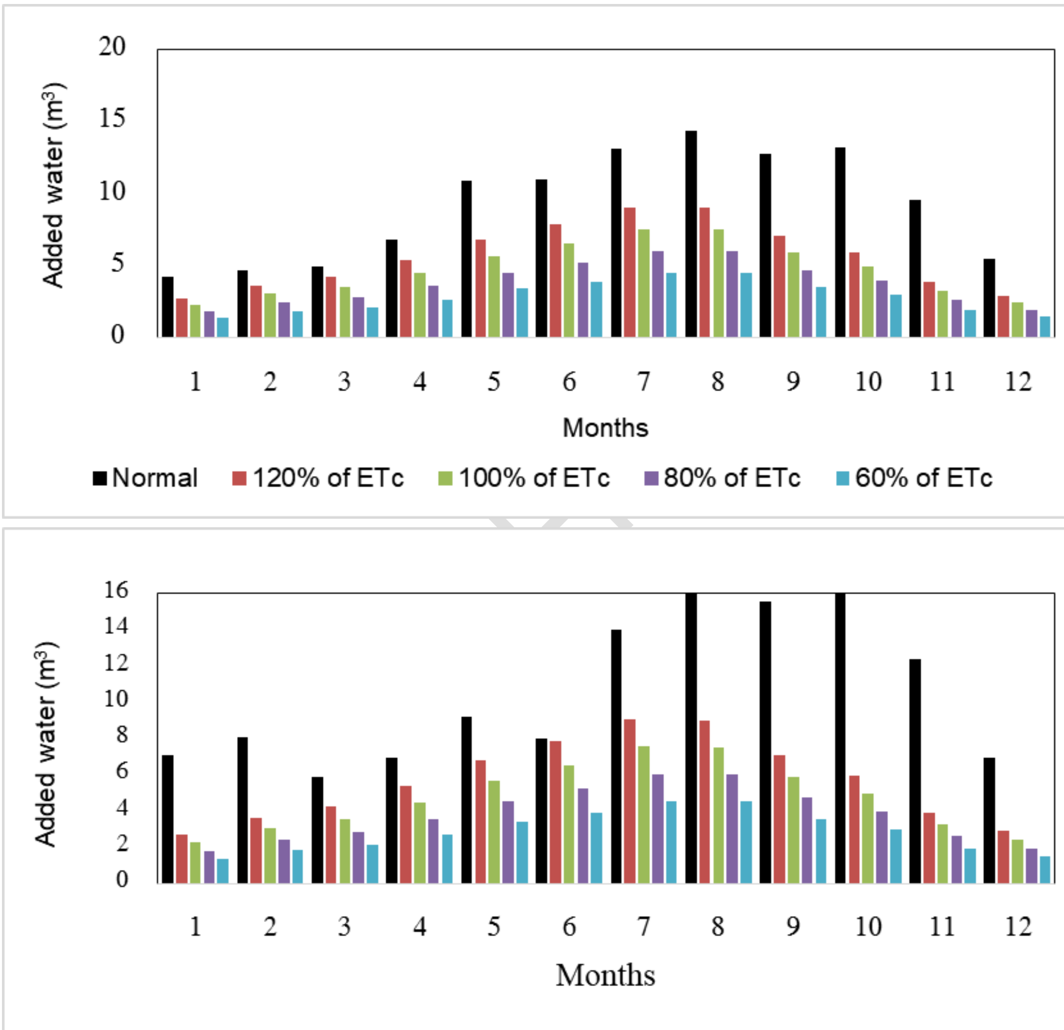

Fig. 1. Comparison between traditional and different deficit irrigation on WR (m^3/month). A: well water and B; treated water

Figure (2) shows the amounts of water calculated using water balance, evaporation pan and Penman Monteith methods through the year. The results indicated that the amount of water calculated by the Penman Monteith method was higher compared to other methods in the months from March to October. These results may be due to the accuracy of the observed meteorological data during this period, and soil in the site has a consistency sandy, which is characterized by low water retention and water loss through evaporation or deep seepage [24, 25].

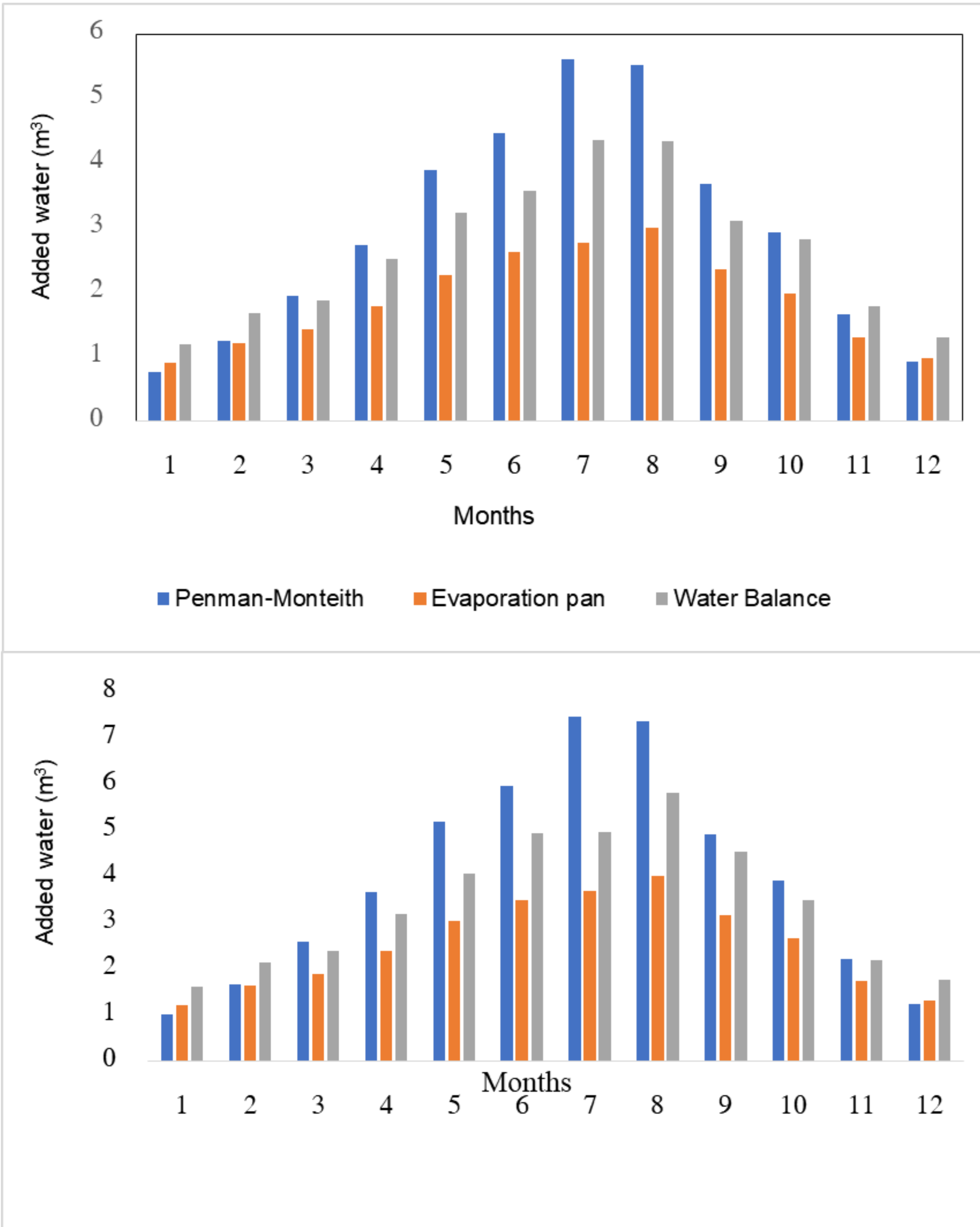

Fig. 2. Monthly water requirements calculated using different equations.

3.2 Expected Decrease In Yield

The results in (Table 3) refer to the expected relative yield of the date calculated from the Mass and Hoffman equation (1977) at 60%, 80%, 100% and 120% ETc using well and treated water quality compared with traditional irrigation (farm). The data shows the relationship between yield and the depth of the irrigation water with the electrical conductivity values estimated from saturated soil paste. The relative production reached 79.82, 83.79, 85.25, 87.74, 85.98% for traditional irrigation (farm) and the maximum possible yield production was 91.81 kg/palm tree, and this gives an indication of the quantity of the yield production against the quantities of water 73.28, 76.92, 78.26, 80.55, 78.93 kg/tree, while the actual results of the actual yield obtained in the experiments were 43.94, 54.29, 68.20, 76.04, 80.43 kg/tree at 60, 80, 100, 120% ETc, respectively, and it is noticeable that the amount of actual yield production is lower compared to that calculated from the equation.

Table 3. Amounts of water added, yield and WUE at different deficit irrigation from well and treated water quality

Deficit irrigation levels	EC (dS/m)	Relative Yield (٪)	Maximum Yield (kg/Tree)	Expected Yield (kg/Tree)	Actual Yield (kg/Tree)
		Well water			
60%	9.61	79.82	91.81	73.28	43.94
80%	8.50	83.79	91.81	76.92	54.29
100%	8.10	85.25	91.81	78.26	68.20
120%	7.40	87.74	91.81	80.55	76.04
Normal	7.78	85.98	91.81	78.93	80.43
		Treated water			
60%	7.06	89.00	89.80	79.93	41.18
80%	5.28	95.39	89.80	85.66	55.21
100%	4.99	96.43	89.80	86.60	67.47
120%	4.85	96.95	89.80	87.06	76.99
Normal	5.38	95.02	89.80	85.33	82.53

Means sharing the same letter in a column do not differ significantly at $p \leq 0.05$.

3.3 Water Use Efficiency (WUE)

The WUE values calculated using well water quality was 1.24, 1.15, 1.16, 1.08, 0.72 kg/m^3, while in the case of treated water was 1.17, 1.17, 1.15, 1.09, 0.64 kg/m^3 at 60, 80, 100, 120% ETc, respectively (Table 4). It is worth noting that the increase in the water amounts used for date palms using traditional irrigation has led to a decrease in the WUE values. Ahmed et al., 2020 [27] reported that the use of deficit irrigation at 50%, 75% and 125% of the water requirements, led to a significant increase in the date palm yield and an improvement in the quality of the fruits, through its positive impact on the WUE compared to the traditional irrigation. He also mentioned deficit irrigation is more suitable for the irrigation of palm trees in arid and semi-arid regions [28, 29].

Table (4). Amounts of water used from well and treated water quality and water use efficiency at different deficit irrigation.

Deficit irrigation level	Well water			Treated water		
	*Amounts (kg/m^3)	Yield (m^3/tree)	WUE (kg/m^3)	*Amounts (m^3/tree)	Yield (kg/tree)	WUE (kg/m^3)
60%	31.76	43.94e	1.38	31.36	41.18e	1.31
80%	40.97	54.29d	1.33	40.47	55.21d	1.36
100%	53.57	68.20c	1.27	53.47	67.47c	1.26
120%	65.60	76.04b	1.16	65.70	76.99b	1.17
Traditional irrigation	108.62	80.43a	0.74	118.82	82.53a	0.70

*Calculated according to water balance method. Means sharing the same letter in a column do not differ significantly at $p \leq 0.05$.

3.4 Soil Moisture Distribution

The results in (Table 5) indicated the soil moisture distribution in the area of the date palm tree at at 60, 80, 100, 120% in addition to the traditional irrigation at depths (0–50), (50–100), 100– 150(and (150–200 cm). The results showed that soil moisture distribution was 17.45% at 60% ETc in the surface layer (0–50) cm, and 19.85, 18.70, 18.11% at depths (50–100), (100–150) and (150–200) cm, respectively. The results also showed that the sub-surface layer at a depth of (50–100 cm) had a higher moisture content compared to the other layers, reaching 19.85% at the 60% Etc. In the traditional irrigation used on the farm, the results showed that the surface layer (0–50 cm) soil moisture content was 19.73%, and in the subsurface layers was 20.08, 20.14, 23.00% at the four depths, respectively, and the differences between the soil moisture content values was significant at 5%. It is noted that the moisture content in the subsurface layers increased compared to the surface layer, which allows to compensate for the loss of water from the surface layers, whether through plants or evaporation from the surface of the soil. There was gradual increase in the moisture content of the soil directly proportional to the increase in the deficit irrigation, however at 120% of Etc, the moisture content of the traditional irrigation was more than water requirements required by date palm. The results are in agreement with those reported by Al-khasha et al., 2019 [17].

Table 5. Effect of different deficit irrigation on soil moisture distribution using well and treated water quality.

Depth (cm)	Well water				
	60%	80%	100%	120%	Traditional irrigation
0-50	17.45b	18.24ab	18.43a	20.34a	21.19a
50-100	19.85a	19.41a	17.83a	21.21a	22.28a
100-150	18.7a	17.65b	17.50a	20.59a	21.41a
150-200	18.11a	16.78b	19.08a	21.70a	20.92a
LSD	1.83	1.48	1.88	2.19	2.72
	Treated water				
Depth (cm)	60%	80%	100%	120%	Traditional irrigation
0-50	14.63b	15.79b	16.9b	18.28b	19.73b
50-100	16.87a	15.06b	18.77ab	22.87a	20.08b
100-150	15.68ab	18.29a	20.15a	19.39b	20.14b
150-200	15.29ab	15.55b	19.29a	18.08b	23.00a
LSD	2.07	1.47	2.08	2.29	2.43

Means sharing the same letter in a column do not differ significantly at $p \leq 0.05$.

3.6 Water Productivity Function

The water productivity function varies according to the farm management and the farmer's ability to apply the required water addition and the type of irrigation system used. It shows the treated water productivity function, was similar to the well water productivity function (Fig. 3). It shows the treated water productivity function, which is similar to the well water productivity function. The strategy of using the water productivity function equation for crops is very important in arid and semi-arid areas due to the scarcity of the water resource used for irrigation in those areas. One of the important ways to express the water function equation is the use of water consumption ratios, or what is termed the use of the deficit irrigation [19, 27, 31]. The results indicate that the well water requirements based on water balance method at 60%, 80, 100, 120% Etc gave an actual productivity: 1.37, 1.7, 2.13, 2.38, 2.51 kg/m^2 using well water and 1.29, 1.73, 2.11, 2.41, 2.58 kg/m^2 using treated water.

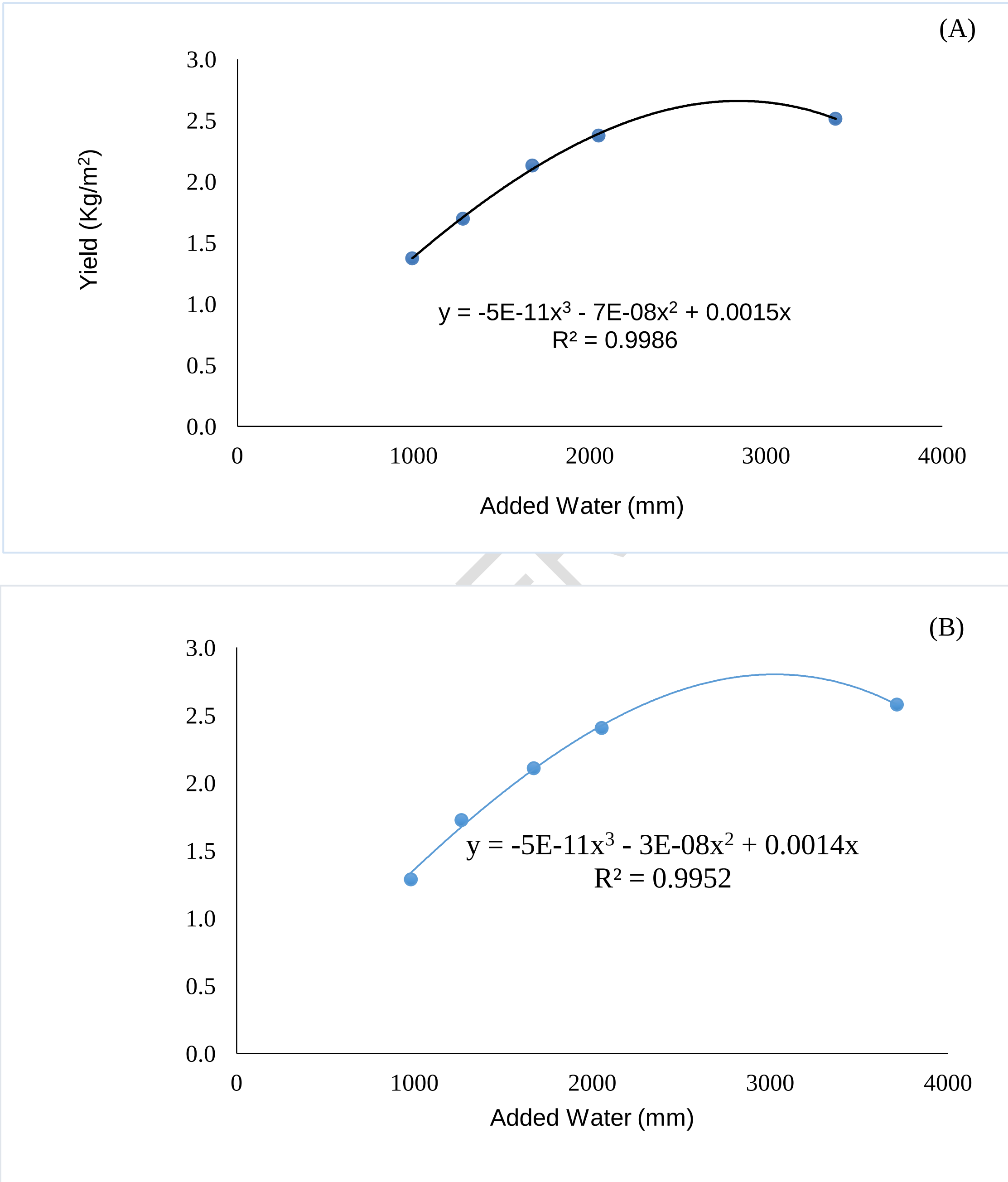

Fig. 3. Water productivity function expressing the actual amount of water added as depth and the actual productivity: (a) for well water (b) for treated water.

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