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Deficit Irrigation Technique to Improve Water Productivity of Avocado Grown on Mulched Sandy Soil

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Abstract: A field experiment was conducted in new reclaimed areas to improve avocado trees water productivity cultivated under deficit irrigation and mulching. The deficit irrigation treatments were 90, 80, 70, and 60% of reference evapotranspiration (ET_o). Results revealed that The average water requirements during different avocado trees physiological growth stages were 613, 1509, 1755, 1391, and 632 m^3/fed for flowering to end of fruit set, fruit set to approximately 50% of the expected market fruit size, during the fruit growth stage, during the fruit ripening stage, and during the flower bud formation stage, respectively. These values represent approximately 10.4%, 25.6%, 29.7%, 23.6%, and 10.7% of the total yearly water requirement. The averages irrigation frequency were 2.45, 2.61, 2.72, 2.87, and 3.91day for 100, 90, 80, 70 and 60% ET_o treatments, respectively. The highest crop water productivity value of 1.24 kg/m^3 water was attained at 70% ET_o followed by 1.18 kg/m^3 water at 80% ET_o while the least crop water productivity (1.06 kg/m^3 water) was realized at 100% ET_o. The crop water requirement of 5110 m^3/fed/year with high irrigation frequency is recommended for mulched sandy soil cultivated with avocado trees.

1 Introduction

Limited water resources are a global dilemma that affects particular countries. In the 1990s, Egypt cross over the threshold water resource value (1000 m^3/capita/year). However, based on population predictions for 2025, the water resource value would decrease to be 500 m^3/capita/year. The major challenge currently facing Egypt is the essential development and management of limited available water resources to congruent the expected population growth (MWRI 2014, FAO 2016).

Avocado water uptake is relatively inefficient due to their extreme root hairs. Therefore, avocados require adequate soil moisture to survive, though too much water can suffocate their roots. Additionally, excessive soil moisture causes suitable condition for avocado root rot fungus (*Phytophthora cinnamomi*) to grow. Also, excessive watering might accumulate more salt in shallow soil depths (Grant 2015).

Carr (2013) reported that both drip and under-tree micro-sprinklers have been/are successfully used to irrigate avocado trees. Mulching of young trees is a recommended water conservation measure and has other benefits.

Deficit irrigation strategies are becoming common in areas where water supplies are limited due to change climatic conditions (Fereres and Soriano 2007). SDI strategies also provide water saving opportunities with minor reduction in crop production. Mirás-Avalos et al (2016) achieved water savings of 43%–65% under deficient irrigation strategies with slightly lower yields but higher product quality. Deficit irrigation is an irrigation practice where a crop is irrigated to level less than crop water requirement and increase water use efficiency. The Deficit irrigation might be practiced at different stages of crop development where full irrigation is applied at critical growth stages and minimum application occurs in noncritical growth stages or by scheduling irrigation to maximize water application efficiency and increase yields per unit of irrigation water applied (Nagaz et al 2012, Geerts and Races 2009). Allen et al (1998) indicated no significant reduction in crop yields in field trials when crops were subjected to certain levels of water stress either during a particular growth period or throughout the growth season. Hence, Gijón et al (2009) reported a reduction in yield by inducing controlled water stress is considered insignificant compared to the benefits gained from diverting water to irrigate additional cropped areas.

This study aims to assess deficit irrigation practices on avocado fruit production and its leaves nutrient contents as well as the water productivity. Also, defined the optimum water requirements for avocado trees (Hass Cultivate with Lula rootstock) cultivated on sandy soil under mulching and drip irrigation in South of Tahreer, Egypt.

2 Materials and Methods

A field experiment was conducted in new reclaimed areas during 2019–2020 growing season at Umm-Sabir farm, plot 23, belongs to Modern Agriculture Company “PICO”, South of Tahreer, El-Boheira Governorate (approximately 150 km NW of Cairo) in order to improve avocado trees water productivity cultivated in sandy soil under deficit irrigation and mulching.

2.1 Study area

The specific study area is located at 30° 32′22.386″N latitude and 30°47′51.082″E longitude and an altitude of 74 m above sea level. The study area is a new reclaimed sandy soil served by drip irrigation system. The irrigation water is delivered to the field by pumping from El-Nasr Canal. The summer growing season is long, hot, arid, and clear, while the winter season is cool, dry, and mostly clear. Throughout the year, the mean temperature typically varies from 34.8°C and is rarely below 8°C (**Table 1**).

2.2 Experimental design

The experimental area is covered with fallen avocado leaves that act as soil mulching. The fruiting avocado trees (Hass cultivar with Lula rootstock) in mulched soil were planted in 4 × 7 area (150 trees/fed). The experiment included five different deficit irrigation treatments (100, 90, 80, 70 and 60% of the reference evapotranspiration, ET_o). Each plot contained 12 trees. The experimental plots were arranged and statistically analyzed using a completely randomized blocks design.

The ET_o was measured in mm/day during the growth season and it estimated using the FAO-56 Penman–Montith (PM) equation as described by Allen et al (1998) based on the weather, soil, and crop parameters. Crop water requirements (WR) were calculated for mulched soil cultivated with fruiting avocado trees using the PM equation as following:

$$ET_o = (0.408\ \Delta\ (R_n - G_d) + \gamma\ U_2\ (e_s - e_a) \times (900 / (T_{mean}+273)) / (\Delta + \gamma\ (1+0.34\ U_2))$$

$$\Delta = 4098 \times ((0.6108 \times \text{Exp}\ (17.27 \times (T_{mean}) / (T_{mean} + 237.3))) / (T_{mean} + 237.3)^2$$

$$R_n = R_{ns} - R_{nl}$$

$$R_{ns} = R_s\ (1-0.23)$$

$$R_{nl} = \sigma(((T_{max}+273.16)^4+(T_{min}+273.16)^4)/2) \times (0.34–0.14\ (e_a)^{0.5}) \times (1.35\ (R_s/R_{so}) - 0.35)$$

$$R_s = R_a\ (0.25 + 0.5\ (n/N))$$

$$N = 24\ \omega_s / \pi$$

$$\omega_s = \arccos\ (-\tan(\text{lat in radian}) \times \tan(\delta))$$

$$R_{so} = R_a\ (0.75 + 2 \times 10^{-5}\ (\text{Elevation}))$$

$$R_a = (1440/\pi\ )\ G_{ca}\ d_r\ (\omega_s \sin(\delta) \sin(\text{lat in radian}) + \cos\ (\text{lat in radian}) \cos(\delta) \sin(\omega_s))$$

$$G_{ca} = (P_s)^2 / (R_s \times P_{rs})$$

$$d_r = 1 + 0.033 \cos(2\pi\ J /365)$$

$$\delta = 0.409 \times \sin((2\pi\ J /365) - 1.39)$$

J	=	$(\pi/180)$ (Lat_{degree} + ($Lat_{minutes}$ /60))
		G_d » 0
γ	=	$0.665 \times 10^{-3} \times P$
P	=	101.3 ((293 – 0.0065 (Elevation)) / 293 $)^{5.26}$
e_s	=	($e°(T_{max})$ + $e°(T_{min})$) / 2
e_a	=	($e^o(T_{min})$ (RH_{max}/100) + $e^o(T_{max})$ (RH_{min}/100)) / 2
e°(T)	=	0.6108 (EXP (17.27 (T) / (T + 237.3))
T	=	T_{min} or T_{max}
WR	=	$4.2 \times ET_o \times KC \times ((1 + LR)/E_i) \times G_{ca} \times R_d \times SDI/100$

where WR is the water requirement in m^3/Fed/period, ET_o is the reference evapotranspiration in mm/day, KC is the avocado crop coefficient, LR is the leaching requirement (0.25), E_i is the irrigation efficiency for the drip irrigation system (0.9), G_{ca} is the green coverage area of avocado trees in the experimental area (0.71 m^2), R_d is the active root depth of avocado trees in the experimental area (0.6 m), SDI is the sustained deficit irrigation treatment, P_s is the distance between trees along drip irrigation lines (i.e., 4 m), P_{rs} is the distance between rows of trees, (i.e., 7 m in this case), RAW is the readily available water, FC is the field capacity in mm, PWP is the permanent wilting point in mm, R_d is the average depth of the active roots in m (0.6 m) for the tested avocado trees. Corresponding irrigation intervals during the day were estimated for irrigation scheduling using 0.25 as allowable water depletion (A_d) during the growth season of mulched soil cultivated with avocado trees. The actual water applied in each irrigation for different treatments and intervals were recorded.

The drip irrigation system contains a main pipeline of polyvinyl chloride (PVC) that is placed on the soil surface with 35 m long and 40 mm wide. The lateral lines with block end were made of black polyethylene (16 mm diameter) with built-in drippers (4 L/h discharge) and 50 cm between lines. To maintain the appropriate humidity around avocado trees, additional sprinkler system was located between trees. Valves (16 mm) were used to control irrigation rates for each treatment, and the added water via sprinkler irrigation system was monitored.

The irrigation system in the experimental area included the following components: (a) the control head located at the water source supply and consists of a 2″/2″ centrifugal pump, an electric engine (pump discharge of 20 m^3/h and 26 m lift), a 2″ screen filter (120 mesh), a backflow prevention device, a pressure regulator, pressure gauges, a flow meter, control valves, and chemical injection, (b) a main line consisting of 50 mm PVC pipes as water conveyance from the source to the manifolds, (c) manifold lines consisting of 50 mm PVC pipes connected to the main line through control valves 1.5″, (d) lateral lines consisting of 16 mm PE tubes connected to manifolds through beginnings installed on manifolds lines, and (e) emitters built in 16 mm PE tubes (24 "GR-Turbo-type" drippers (4 L/h per tree) at 1.2 bar, i.e., 3600 drippers per feddan or 14.4 m^3/fed-h) as shown in **Fig 1**.

Avocado trees in the experimental area were fertilized during different growth stages using a fertigation system at the recommended rates of PICO farm experts. Where the total nutrient requirements during avocado growth season were about 60, 8, 75, 13, 7, 2.4, 1.2 and 0.6 kg/fed N, P_2O_5, K_2O, CaO, MgO, Fe, Zn and Mn respectively (Ibrahim 2013b).

2.3 Field data

To assess the effects of different deficit irrigation treatments on the vertical and horizontal distribution of soil moisture and salt accumulation, soil samples were collected from 25, 50, 75, and 100 cm soil depths and at distances of 50, 100, 150, and 200 cm away from the tree trunk and parallel to the lateral lines. The amount of added irrigation water during the growth season was recorded for each experimental plot.

Representative soil and water samples were collected for physical and chemical analyses (**Table 2**). The electrical conductivity was determined in 1:2.5 Soil:Water extract ($EC_{1:2.5}$) using an electrical conductivity meter (Model YSI 32). The soil water soluble K, Ca, Mg, Na, and Cl were also determined in 1:2.5 Soil:Water extract using standard chemical analysis methods according to Jackson (1958). Available P was determined using Olsen method as described by Jackson (1958). For the effects of SDI treatments on element contents of avocado trees, leaf samples 5–7 months age were collected and chemically prepared to determine its content of N, K, Ca, Mg, Na, and Cl using methods described by Jackson (1958).

Crop water productivity as crop production per unit amount of water used (Molden et al 2010) will be calculated to evaluate crop water use efficiency under different SDI treatments. The avocado fruit yields for each treatment were recorded and avocado water productivity (CWR) was calculated using crop yield (CY) and total water requirement (TWR) as follows:

$$CWP \text{ in kg/m}^3 = CY \text{ in kg/fed} / TWR \text{ in m}^3\text{/fed}$$

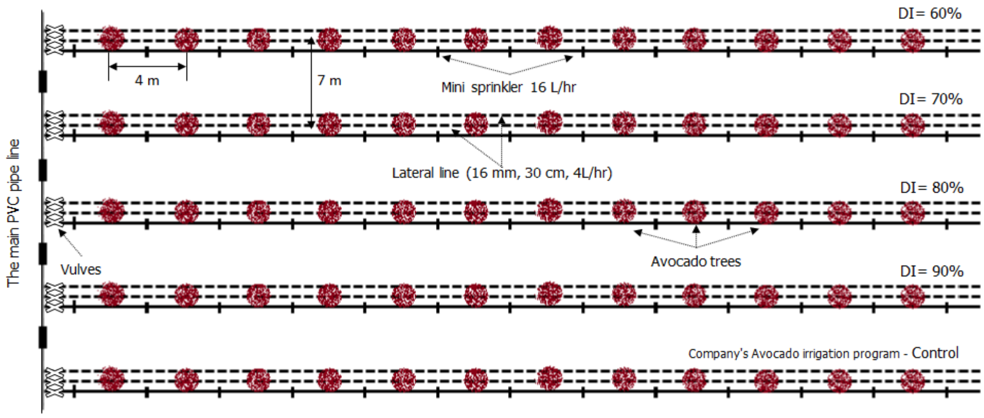


Fig 1. layout of the experimental area

3 Results and Discussion

3.1 Crop Evapotranspiration (ETc)

Some meteorological data of South of Tahreer, El-Boheira Governorate, during the growing season (**Table 1)** were employed to calculate ET_o values using PM equation as described by Allen (1998). The average air temperature values (minimum, maximum and mean) and the relative humidity (minimum, maximum and mean) during 2018–2019 growing season were 22.8°C, 29.6°C, and 15.9°C, and 46.1%, 74.0%, and 32.7%, respectively. The average wind speed (U) values for day, night and their mean) during the year were 3.9, 5.0, and 2.84 km/h, respectively. The annual average solar radiation (R) value was 12.9 MJ/m^2 with the highest values of 16.4 MJ/m^2 from May to July. Ibrahim (2013a) recommended using a metrological-based method for optimizing the amount of applied water that would maintain crop production and increase CWP.

The soil texture of the experimental site was sand and the infiltration rate is ranged from 18.9 to 16.5 mm/h with average value of 17.6 mm/h (**Table 2**). The infiltration rate values are expected for such sandy soil based on soil textural classifications of WDE (2001).

The soil salinity is slightly saline ($EC_{1:2.5}$ = 0.26 dS/m). The average values of soil moisture contents at saturation, field capacity, permanent wilting point and soil bulk density were 16.5%, 7.63%, 4.27% and 1.56 g/cm^3, respectively. The irrigation water is fresh water with low salinity (EC_w = 0.33 dS/m) that is delivered from El-Nasr canal. These results showed that there were no harmful effects of soil or irrigation water properties on avocado trees growth and their production.

The average values of avocado trees coefficient (KC), leaching requirement, drip irrigation system efficiency and its discharge rate to calculation avocado trees WR of were 0.6, 25%, 90%, and 9.6 m^3/fed/h, respectively (**Table 3**). The average ET_o value of avocado trees was 8.67 mm/day.

3.2 Water requirements for avocado trees under deficit irrigation treatments

The irrigation water requirement (WR) for mulched soil cultivated with fruiting avocado trees and the irrigation frequency for sustained different deficit irrigation (SDI) treatments are shown in **Table 4**. The obtained results indicate that the WR amounted for 7319, 6737, 5935, 5072, and 4441 m^3/fed/season for avocado trees grown under 100, 90, 80, 70 and 60% ET_o treatments, respectively. It was observed a positive effect of deficit irrigation treatments on water savings, particularly at 90, 80, and 70%, without any adverse effects on avocado trees growth and their production. The amounts of saved water were 581, 1384, 2246 and 2878 m^3/fed/season for 90, 80, and 60% SDI, respectively compared to full irrigation amount (100% ET_o). These results agreed with those obtained by Singh (2020), Montazar et al (2020).

The averages irrigation frequency were 2.45, 2.61, 2.72, 2.87, and 3.91day for 100, 90, 80, 70 and 60% ET_o treatments, respectively (**Table 4**). The average amounts of irrigation water during different physiological avocado trees growth stages were 613 from flower spikes exit to fruit set end, 1509 from fruit set to 50% of the expected market fruit size, 1755 during the fruit growth stage, 1391 during the fruit ripening

Table 1. The meteorological data of South of Tahreer, El-Boheira Governorate

Month	T_{mean}	T_{max}	T_{min}	RH_{mean}	RH_{max}	RH_{min}	U_{mean}	Ud	Un	n	R	P
	°C			%			%			hrs/day	MJ/m^2	mm/d
Jan	13.1	18.4	7.9	57.1	76.6	34.6	3.62	4.27	2.38	9.2	8.8	0.5
Feb	14.7	20.7	8.8	49.3	72.1	32.1	3.64	5.05	2.87	9.5	10.6	0.3
Mar	17.5	24.5	10.5	45.4	73.0	33.8	4.56	5.40	2.86	10.6	13.0	0.0
Apr	21.8	29.7	13.8	38.3	70.5	30.9	4.22	5.86	3.62	11.5	15.0	0.0
May	26.3	34.6	18.1	34.9	71.6	30.6	4.16	5.64	3.11	12.8	16.3	0.0
Jun	29.2	37.6	20.8	36.2	72.1	33.1	3.99	6.08	3.37	13.7	16.3	0.0
Jul	30.2	38.4	22.1	40.5	71.5	34.7	3.95	5.23	3.15	13.5	16.3	0.0
Aug	30.7	38.5	22.8	40.3	73.9	36.4	3.48	4.93	2.85	12.0	16.3	0.0
Sept	28.1	35.2	21.0	47.6	74.5	27.4	3.95	4.35	2.46	10.5	13.7	0.0
Oct	24.6	30.7	18.4	52.1	75.6	31.5	3.87	4.47	2.56	10.1	11.5	0.0
Nov	21.3	26.6	16.0	57.0	76.9	31.9	3.34	3.97	2.07	9.3	9.3	0.0
Dec	15.5	20.4	10.5	54.6	79.7	35.6	3.48	4.15	2.09	8.9	8.1	0.2
Mean	22.8	29.6	15.9	46.1	74.0	32.7	3.9	5.0	2.8	11.0	12.9	0.1

These meteorological data were collected by the agrometeorological station installed in PICO farm

Table 2. Some physical and chemical soil properties of the experimental area

Soil depth cm	Physical properties										
	SP	FC	PWP	TAW	Infiltration rate mm/h	Bulk density g/cm^3	$CaCO_3$	Sand	Silt	Clay	Soil Texture
	%						%	%			
0–25	16.8	8.1	4.4	3.7	18.9	1.61	1.85	88.5	7.70	3.80	Sandy
25–50	16.6	7.7	4.3	3.4	17.4	1.52	2.10	90.7	6.50	2.80	Sandy
50–75	16.2	7.1	4.1	3.0	16.5	1.55	2.40	90.8	6.10	3.10	Sandy
Mean	16.5	7.6	4.3	3.4	17.6	1.56	2.12	90.0	6.77	3.23	Sandy

Chemical properties

	OM %	$pH_{1:2.5}$	$EC_{1:2.5}$ dS/m	Salinity ppm ppm	Ca^{++}	Mg^{++}	Na^{+}	HCO_3^{-}	$CO_3^{=}$	Cl^{-}	$SO_4^{=}$
					Meq/l						
0–25	0.19	7.9	0.24	154	0.92	0.40	1.10	0.21	--	1.85	0.34
25–50	0.15	8.1	0.28	179	0.95	0.55	1.32	0.31	0.15	1.90	0.44
50–75	0.11	8.1	0.27	173	0.95	0.50	1.25	0.25	0.15	1.95	0.35
Mean	0.15	8.03	0.26	169							
Chemical properties of irrigation water											
		7.8	0.33	211	1.18	0.48	1.64	0.30	--	2.35	0.66

Table 3. Crop coefficient (KC), PM's reference ET_o, and actual crop evapotranspiration (ET_c)

Month	Period days	ET_o mm/day	KC	SDI - %ET_o				
				100	90	80	70	60
				Liters/tree/day				
Jan	15	3.44	0.46	26.4	23.7	21.1	18.5	15.8
	16	3.91	0.44	28.7	25.8	22.9	20.1	17.2
Feb	15	5.15	0.44	37.8	34.0	30.2	26.4	22.7
	14	4.44	0.48	35.5	32.0	28.4	24.9	21.3
Mar	15	5.81	0.52	50.4	45.3	40.3	35.2	30.2
	16	5.57	0.55	51.1	46.0	40.9	35.7	30.6
Apr	15	9.83	0.55	90.1	81.1	72.1	63.1	54.1
	15	9.76	0.55	89.5	80.5	71.6	62.6	53.7
May	15	11.2	0.59	109	98.1	87.2	76.3	65.4
	16	11.6	0.65	125	112	100	87.5	75.0
Jun	15	13.0	0.71	155	139	124	108	92.8
	15	14.4	0.76	183	165	146	128	110
Jul	15	13.3	0.77	172	155	137	120	103
	16	14.0	0.77	180	162	144	126	108
Aug	15	13.3	0.76	169	152	135	118	101
	16	11.3	0.75	140	126	112	98.3	84.3
Sept	15	11.6	0.73	140	126	112	98.1	84.1
	15	9.78	0.71	116	105	93.0	81.4	69.8
Oct	15	8.49	0.70	99.2	89.3	79.4	69.5	59.5
	16	8.35	0.63	87.4	78.7	70.0	61.2	52.5
Nov	15	6.68	0.50	55.3	49.8	44.3	38.7	33.2
	15	4.81	0.46	36.9	33.2	29.5	25.8	22.1
Dec	15	4.38	0.48	35.4	31.9	28.3	24.8	21.2
	16	3.82	0.47	30.0	27.0	24.0	21.0	18.0
Mean		8.67	0.60	93.5	84.1	74.8	65.4	56.1

stage and 632 m^3/fed/day during the flower bud formation stage (**Table 5**). The crop water applied represented approximately 10.4%, 25.6%, 29.7%, 23.6%, and 10.7% of the total annual crop water applied for the corresponding physiological growth stages.

3.3 Soil salinity distribution under different deficit irrigation water

Salt distribution under mulched soil cultivated with fruiting avocado trees under deficit irrigation water is shown in **Fig 2**. Results revealed that the soil salinity ($EC_{1:2.5}$) values slightly increased from 0.24 dS/m at 100% ET_o to 0.3, 0.4, and 0.54 dS/m at 90, 80, and 70% ET_o, respectively. Soil salinity increased to 1.04 dS/m when SDI reached to 60% ET_o. However, these increases in soil salinity occurred by increasing SDI levels up to 60% ET_o level, which had visible adverse effects on growth or production of avocado trees as explained by Lazare et al (2021) whom stated that increasing the SDI level up to 60% has a negative effect on nutrient contents in avocado leaves.

Salt distribution through soil depths along tree trunk parallel to drip lines as influenced by different deficit irrigation treatments is shown in **Fig 3**. The data revealed that high salt accumulation was found in subsurface soil layers (25–75 cm) compared to the surface layer (0–25 cm). These increments in salt accumulation were more pronounced under the 60% ET_o treatment. The data indicate that salt accumulation gradually increased with increasing distance away from the tree trunk. The average soil salinity values of 100, 150, and 200 cm away from the tree trunk were 0.56, 0.8, and 2.23 dS/m, respectively.

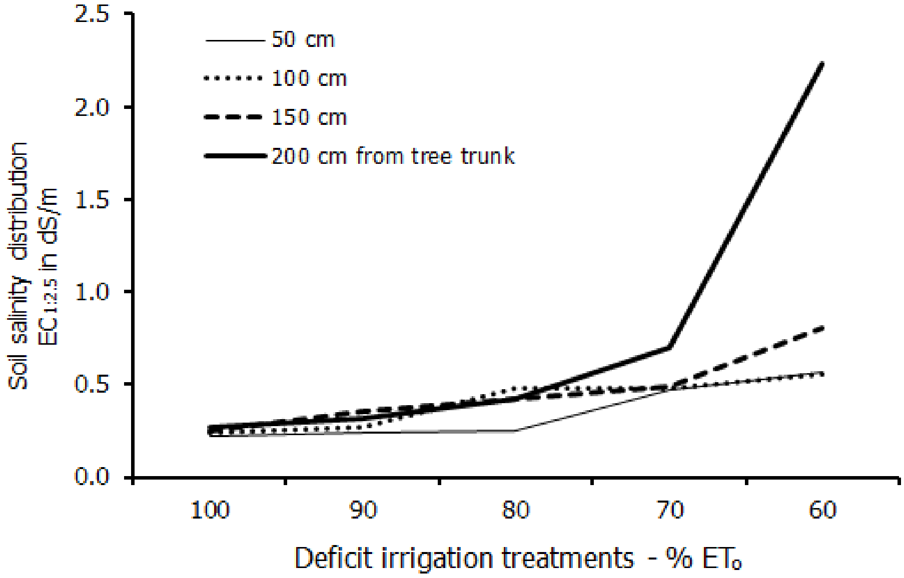
The occurrence of increasing salt accumulation in the subsurface compared to surface layers (in particular, far away from the tree trunk) indicated that the applied irrigation water at different deficit irrigation treatments caused relatively high leaching requirements. These results might be ascribed to the installation of a drip irrigation system with 24 drippers of

Table 4. Water requirements and frequency of avocado tree irrigation under different ET_o treatments

Month	Period Day	SDI - %ET_o									
		100	90	80	70	60	100	90	80	70	60
		Water requirements in m^3/fed/period					Frequency of irrigation days				
Jan	15	86.4	75.6	64.8	57.6	50.4	5	5	5	7.5	7.5
	16	101	86.4	75.6	64.8	57.6	4	5	5	5	8
Feb	15	119	108	97.2	86.4	75.6	5	5	5	5	5
	14	108	97.2	86.4	86.4	64.8	5	5	5	5	7
Mar	15	162	144	126	108	97	3	3	3	3	5
	16	180	162	144	115	108	3	3	4	4	5
Apr	15	297	270	243	189	180	2	2	2	2	3
	15	297	270	243	189	180	2	2	2	2	3
May	15	324	324	270	243	216	1	1	2	2	2
	16	461	403	346	297	259	1	1	1	2	2
Jun	15	486	432	378	324	297	1	1	1	1	2
	15	594	540	486	432	432	1	1	1	1	1
Jul	15	540	486	432	378	324	1	1	1	1	1
	16	634	576	518	403	346	1	1	1	1	1
Aug	15	540	486	432	378	346	1	1	1	1	1
	16	461	461	403	346	288	1	1	1	1	2
Sept	15	432	432	378	324	270	1	1	1	1	2
	15	378	324	297	270	216	1	1	2	2	2
Oct	15	324	297	270	216	216	1	2	2	2	2
	16	288	288	230	202	101	2	2	2	2	4
Nov	15	180	162	144	126	108	3	3	3	3	5
	15	119	108	97.2	86.4	72.0	5	5	5	5	7.5
Dec	15	108	108	86.4	75.6	72.0	5	5	5	5	7.5
	16	101	97.2	86.4	75.6	64.8	4	5	5	5	8
Total		7319	6737	5935	5072	4441	2.45	2.61	2.72	2.87	3.91
%		100	92.1	81.1	69.3	60.7	100	1.14	1.19	1.25	1.71
		Water saving									
m^3/fed/season		0	581	1384	2246	2878					

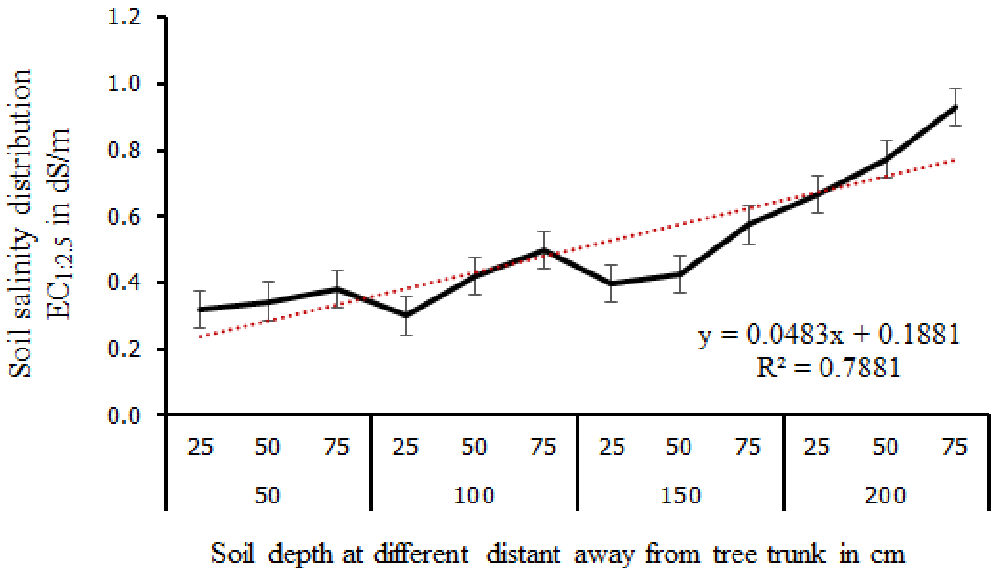
Table 5. Water requirements (WR) for different physiological growth stages of avocado trees under various deficit irrigation treatments in sandy soil

Physiological growth stages	Month	Growth Period Day	SDI - %ET_o					
			100	90	80	70	60	Mean
			Avocado WR in m^3/fed/period					
From exit of the flower spikes to fruit set - %	15/3 to 30/4	46	774	702	630	493	468	613
		12.6	10.6	10.4	10.6	9.7	10.5	10.4
From fruit set to 50% of the expected fruit size - %	1/5 to 30/6	61	1865	1699	1480	1296	1204	1509
		16.7	25.5	25.2	24.9	25.6	27.1	25.6
During the fruit growth period - %	1/7 to 30/8	62	2174	2009	1786	1505	1303	1755
		16.9	29.7	29.8	30.1	29.7	29.3	29.7
During the fruit ripening period - %	1/9 to 30/11	91	1721	1611	1417	1224	983	1391
		24.9	23.5	23.9	23.9	24.1	22.1	23.6
During the flower bud formation period - %	1/12 to 15/3	106	785	716	623	554	482	632
		29.0	10.7	10.6	10.5	10.9	10.9	10.7
Total season from exit of the flower spikes to fruit set	1/1 to 31/12	366	7319	6737	5935	5072	4441	5901
		100	100	100	100	100	100	100



LSD0.05: 0.21 dS/m for SDI, 0.24 dS/m for distance from tree trunk and 0.46 dS/m for soil depth

Fig 2. Distribution of soil salinity ($EC_{1:2.5}$ in dS/m) at different SDI treatments



LSD0.05: 0.21 dS/m for SDI, 0.24 dS/m for distance from tree trunk and 0.46 dS/m for soil depth

Fig 3. Distribution of soil salinity ($EC_{1:2.5}$ in dS/m) at different soil depths and distances from the tree trunk

4 L/h for each tree (96 L/Tree/h). These results are in agreement with those observed by Fereres and Soriano (2007) whom found yield reduction due to SDI in some crop species. Another consequence of SDI is the greater risk of increased soil salinity due to reduced leaching requirements.

3.4 Some elements distribution in soil under different deficit irrigation

Available P and soluble K, Ca, Mg, Na, and Cl distribution through soil depths and at various distances away from tree trunk as a function of different SDI treatments are shown in **Fig 4**. The results revealed that available phosphorus distribution was insignificantly affected by neither different SDI treatments nor distance away from the tree trunk (**Fig 4**). This may be due to the relatively low mobility of phosphorus in soil as reported by Frnossard et al (1989).

The K, Ca, Mg, Na, and Cl distribution in mulched soil cultivated with fruiting avocado trees (**Fig 4)** indicated a slight increase in their concentrations due to the increase in SDI levels without any harmful effects on avocado growth or fruit production. There were significant increases in the accumulation of water-soluble K, Ca, Mg, Na, and Cl in soil for the 60% ET_o treatment. These increases could lead to impacts on growth and production of avocado trees based on known sensitivity to salts in growth medium (Lazare et al 2021).

3.5 Some elements in avocado leaves as affected by different deficit irrigation

The effects of different SDI treatments on contents of N, P, K, Ca, Mg, Na, and Cl in avocado leaves are shown in **Fig 5**. The results indicated that the N, P, Ca, and Mg contents were insignificantly affected by different SDI treatments. Overall, these results reflect the effect of deficit irrigation treatments on the distribution of elements in the soil, which showed slight increases with increasing SDI treatments. However, the results revealed that the accumulation of these elements in the distance between trees had insignificant effect on uptake by plants.

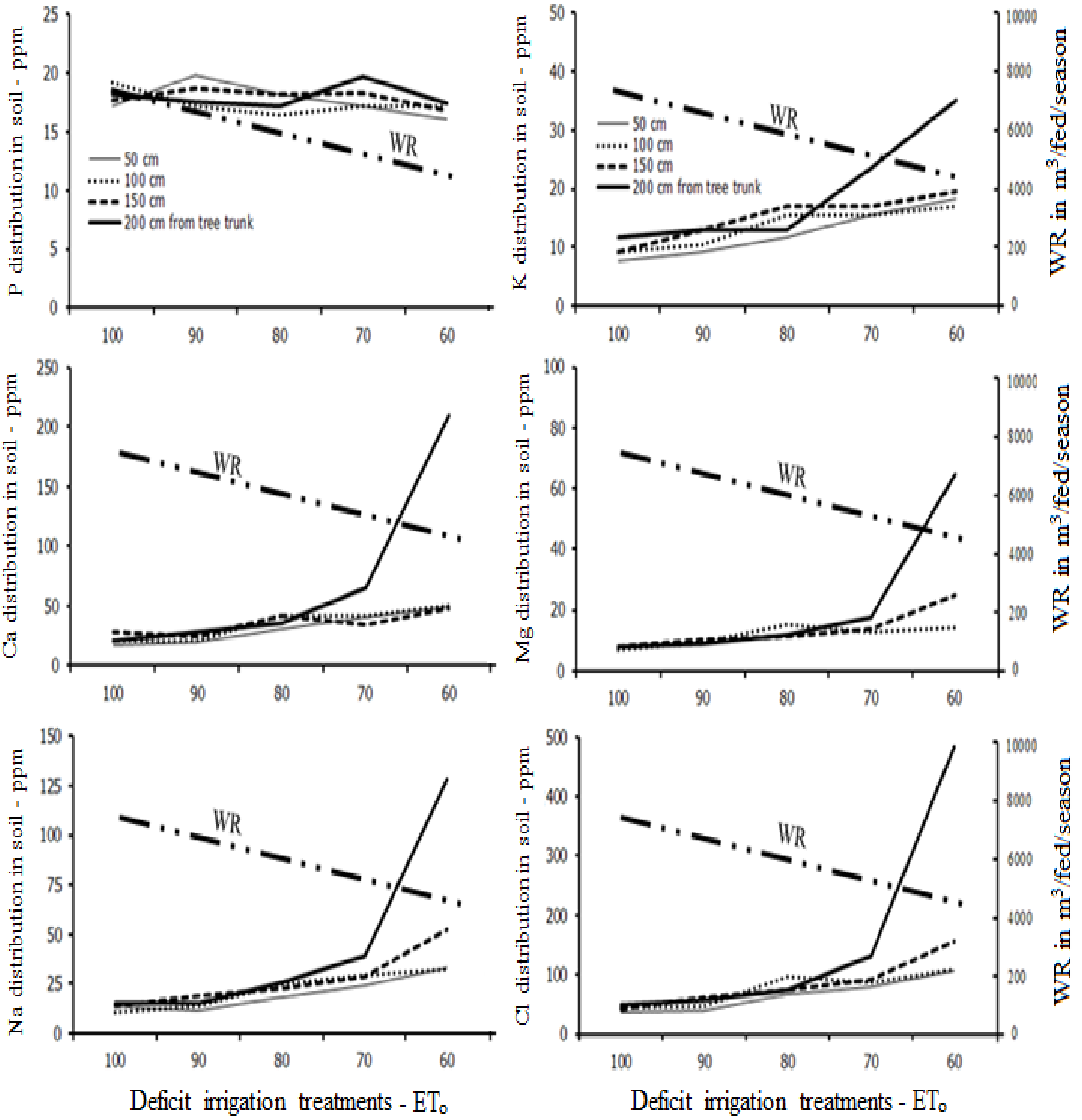
The soil moisture content is reduced by evapotranspiration while some Na and Cl salts remain in the soil. With succession irrigation occurrences, elements may accumulate and build to an excess level for the avocado trees. For example, the undesirable effect of chloride accumulation in leaves reduces the leaf surface and burns its edges, which results in an early dropping of foliage and a reduction of potential tree fruit (Elwood 1960).

There was only a slight increase in the content of K, Na, and Cl in avocado leaves, particularly at the 60% ET_o treatment. These results are due to the concentration effect from water stress associated with this level of SDI and the previously observed accumulation of these elements particularly between tree trunks. This result agrees with that obtained by Abrisqueta et al (2011) whom demonstrated advantages of deficit irrigation strategies regarding water use efficiency and no harmful effect on leaf mineral nutrition was noted.

3.6 Avocado crop yield and water productivity as affected by different deficit irrigation

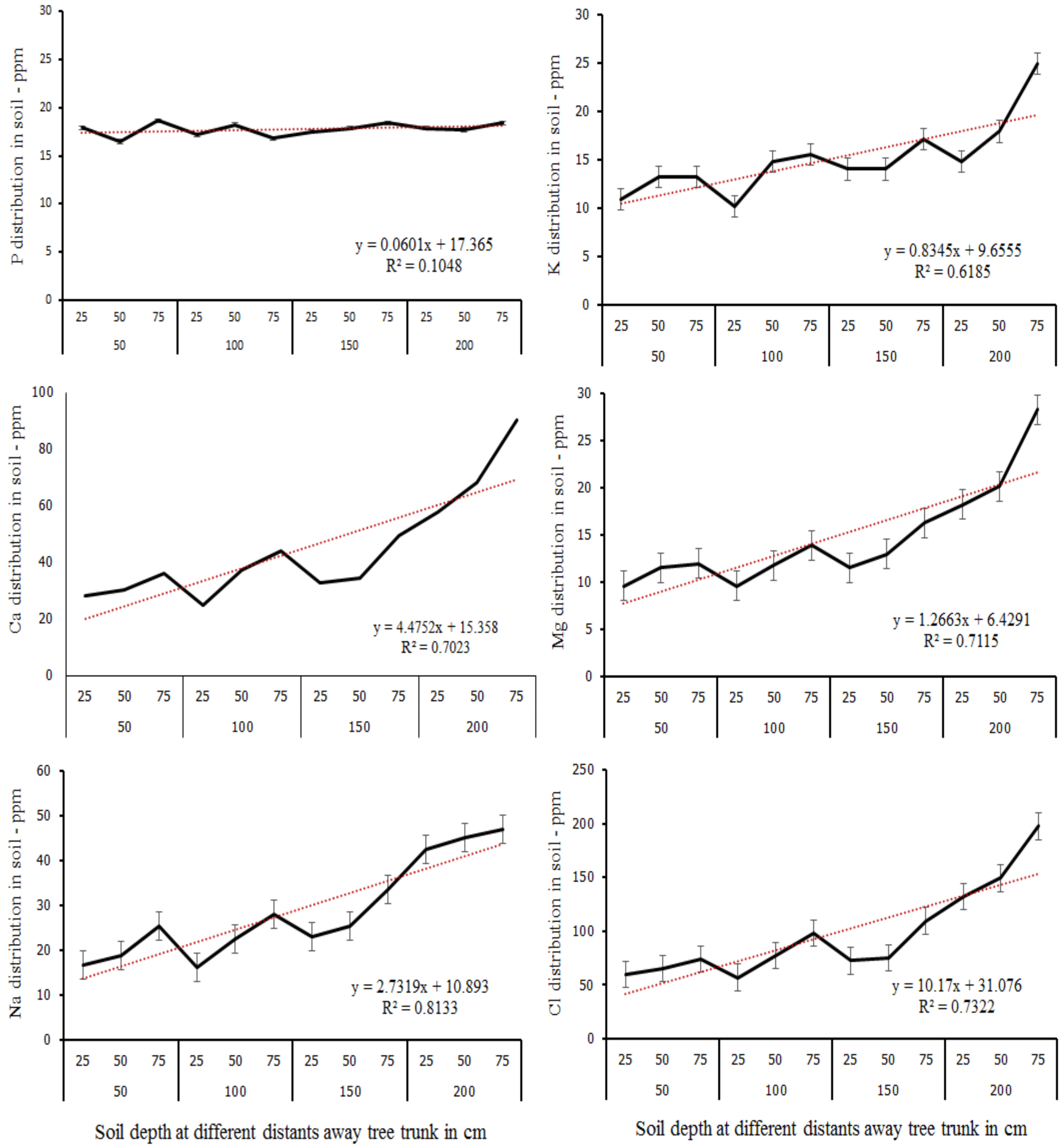
The growth parameters of mulched soil cultivated with avocado trees in response to the different SDI treatments are presented in **Table 6**. The data revealed that the fruit yield of mulched soil cultivated with avocado trees significantly decreased with increasing SDI treatments. The relative decrements in fruit yield were approximately 3.0, 11, 18 and 35% with 90, 80, 70 and 60% of ET_o, respectively. This decrease in avocado fruit yield was highly significant at 60 SDI-% ET_o. These results are in agreement with that observed by Mirás-Avalos et al (2016) who find that the deficit irrigation strategies provide significant opportunities to save water without compromising production. They also added that many researchers report 43% to 65% water savings under deficit irrigation treatments with slightly lower yields, but higher product quality.

The crop water productivity was increased for all deficit irrigation treatments. This increase was more pronounced for the 70% ET_o treatment since it increased by approximately 17%. The crop water productivity of fruit yield decreased for all deficit irrigation treatments. This decrease was also more pronounced at 70% SDI treatment since it was approximately 85.6%. However, avocado fruits of all SDI treatments were of good quality for exporting, even for the lowest SDI level (60% ET_o).



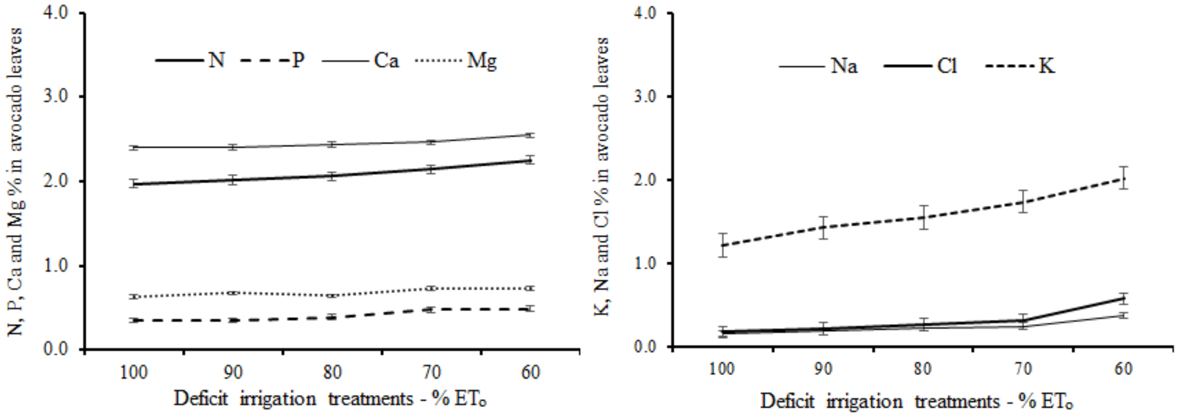
LSD$_{0.05}$: 0.8, 4.6, 15.8, 4.1, 20.6 and 55.9 ppm P, K, Ca, Mg, Na and Cl respectively for SDI

Fig 4. Distribution of available P and water-soluble K, Ca, Mg, Na, and Cl in mulched soil under different SDI treatments



$LSD_{0.05}$: 0.77, 4.5, 11.2, 6.9, 15.2 and 21.7 ppm P, K, Ca, Mg, Na and Cl respectively for distance from tree trunk
$LSD_{0.05}$: 3.6, 9.46, 4.3, 4.2, 4.1 and 16.3 ppm P, K, Ca, Mg, Na and Cl respectively for soil depth

Fig 5. Distribution of available P and water-soluble K, Ca, Mg, Na, and Cl in mulched soil under different soil depths and distant away from the tree trunk.



LSD$_{0.05}$: 0.14, 0.14, 0.33, 0.14, 0.07, 0.15 and 0.22% of N, P, K, Ca, Mg, Na and Cl respectively

Fig 6. Effects of SDI treatments on element contents in leaves of avocado trees

Table 6. Deficit irrigation treatments effects on avocado water productivity

Growth parameters	Units	SDI - %ET$_o$					Mean
		100	**90**	**80**	**70**	**60**	
Total water requirements	m^3/Fed/year	7300	6570	5840	5110	4380	5840
Fruit yield	kg/tree	51.8	50.0	46.1	42.3	33.5	44.7
	Ton/fed	7.76	7.50	6.91	6.35	5.03	6.71
	%	100	97	89	82	65	86
Water productivity	kg fruit yield/m^3	1.06	1.14	1.18	1.24	1.15	1.16
	%	100	107	111	117	108	109

LSD$_{0.05}$: 1.49 Ton/fed and 0.051 kg fruit yield/m^3

4 Conclusion

According to the crop water productivity, the irrigation water applied of 5110 m^3/fed/year with a high frequency of irrigation is recommended for mulched sandy soil cultivated with drip irrigated avocado trees.

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