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Effects of Drip Irrigation Design on a Lemon and a Young Persimmon Orchard in Semi-Arid Conditions

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Abstract: Drip irrigation is presently widely recognized as the most efficient irrigation system that can be used in woody perennial crops. However, uncertainties exist on the more appropriate agronomic design to employ. Here, we summarized the research carried out for three seasons in two young woody perennial crops (persimmon and lemon) in southeastern Spain. Several irrigation designs were compared by maintaining a similar amount of water application but varying the number of emitters and pipelines in each row in the orchard. In the lemon trial, the agronomic irrigation design was additionally combined with different irrigation regimes, comparing full irrigation (FI) with sustained deficit irrigation (SDI). In the persimmon trees, which were still at the juvenility stage, varying the number of emitters per tree or the number of drip lines per tree row, neither affects tree performance nor fruit yield in two out of the three seasons. However, over the entire experimental period, the relative trunk growth increased when more emitters were employed. In the lemon trial, carried out with trees that had reached commercial production, the FI, compared with SDI, increased trunk growth and average fruit weight, while a reduced number of fruits per tree without affecting total yield was observed in the third year of experimentation. The number of emitters per tree only had an effect the first year, increasing lemon fruit weight when the number of drippers per tree increased. In addition, fruit composition was not consistently affected by the irrigation design. It is concluded that, for a given irrigation dose, irrigation frequency, and soil conditions (loam-clay texture), in both very young and more mature trees, increasing the number of emitters or the wetted area only had some slight positive effects on tree performance.

Keywords: deficit irrigation; emitters; irrigation scheduling; water stress

1. Introduction

Drip irrigation is a water delivery technology that increases irrigation efficiency by decreasing soil evaporation and reducing the wetting of the soil surface when compared with other surface or solid sprinkler irrigation methods [1]. In addition, high-frequency drip irrigation allows maintaining the tree crop's water status under more optimum conditions, as compared with low-frequency irrigation systems [2]. Despite the widespread introduction of drip irrigation in the past 40 years and the general suggestions on the amount of the soil area to be wetted that is normally found in irrigation manuals [3], particularly in woody perennial crops, there are still doubts about the optimum soil area to be wetted. This important aspect, as well as the frequency of irrigation, should be considered, as the wetted soil area will affect the soil hydraulic conductivity, tree transpiration, and the possible water leaching due to deep percolation [4]. In this regard, soil texture plays an important role [5]; because of their increased infiltration rate, sandy soils will require a larger wetted surface, higher irrigation frequencies, and lower irrigation doses than heavy clay soils. An incorrect agronomic design in the installation of the drippers (number of drippers per tree and the flow rate) that does not account for the soil texture may invalidate proper irrigation scheduling, resulting in a loss of irrigation efficiency. For example, in a sandy-based soil, if the wetted area of the soil is too small and irrigation timings are too long, water will be lost by deep percolation [6]. Or in a clay-based soil, if the irrigation system wets a large proportion of the soil system, direct evaporation from the soil may increase, particularly when the wet soil surface areas are not shaded by the tree crown, thereby affecting the overall orchard water balance and irrigation efficiency [7]. For instance, in a sandy loam soil, a previous work carried out with apple trees, using different numbers of emitters per tree and varying the irrigation frequency, did not find clear advantages when increasing the number of emitters [8]. Very recently, Lecaros-Arellano et al. [9], in a study with apple trees, reported that in a clay-loam soil, the best tree performance was obtained when a single drip line was used. On the other hand, when similar testing was carried out in a stonier soil with lower soil water holding capacity, the use of up to three drip lines per row of trees was preferred [9].

Previous studies have been carried out mainly at two levels: (i) focusing on the tree eco-physiology responses to varying wetted soil areas, using both experimental and modeling approaches [4,10], (ii) at the agronomic level, by determining tree performance in terms of yield and fruit quality in response to the irrigation agronomic design [11]. Recently, Espadafor et al. [10] in almond and Morales-Sillero et al. [12], in olive, both in orchards with a sandy loam soil texture, demonstrated that plant hydraulic resistance was lowered when the wetted soil volume increased, and this could improve the midday leaf water potential. However, when field agronomic studies were carried out, such as the recent one by Conesa et al. [11] with a clay loam soil texture, the final advantages of increasing the number of drip lines could not be demonstrated, and no clear differences could be detected regardless of the number of drip lines per orchard row employed. When the entire orchard floor was wetted, using micro-sprinklers instead of drip irrigation, tree performance increased, as outlined by Bryla et al. [2].

With this previous information in mind, the objective of this work was to determine the agronomic responses to the soil wetted area of two young orchards of persimmon and lemon fruit trees grown under semi-arid conditions in a clay loam-based soil using different drip irrigation designs. The main hypotheses to be tested were that: (1) in young orchards, where the shaded surface of the soil is still limited, due to the small canopy volume of the trees and soil evaporation is high, increasing the soil wetted area may not provide any additional benefit for tree performance, as compared to a single drip line, and (2) when deficit irrigation is applied, thus reducing the wetted area could lead to a more efficient water application improving plant water status and tree productivity.

2. Materials and Methods

2.1. Experimental Conditions and Plant Material

The field trials were carried out for 3 seasons in the experimental farm "Tres Caminos", belonging to the CEBAS-CSIC, located in the area of La Matanza de Santomera (Murcia, Spain); 38°06′15″ N; 1°01′5″ W. The experiments started in June 2017 and were concluded in 2019, after fruit harvesting.

The study with the evergreen trees was carried out on 6-year-old Fino 95 lemon trees (*Citrus lemon*) grafted on Macrophylla (*Citrus Macrophylla*) rootstock with a 6 × 7 m plant spacing. The trial with the deciduous trees was carried out in a 2-year-old persimmon orchard (*Diospyros Kaki*), cv. "Rojo Brillante", grafted on Lotus rootstock (*Diospyrus Lotus*), with a 3 × 5 m plant spacing.

The soil in the farm was a clay-loam soil (34% sand, 34% silt, 32% clay) with an average organic matter content of 2.9%. The irrigation water was slightly saline (Table 1), as normally found in the area of study because of sea intrusion into the underground waters mainly used for irrigation. The area is, in fact, characterized by semi-arid conditions with average annual reference evapotranspiration (ET_o) and rainfall of 1229 and 269 mm, respectively.

Table 1. Chemical composition of the water used for irrigation. Data shown are average values from several samples collected during the entire experimental period.

				mg L^{-1}			
pH	7.9 ± 0.1	Cl^-	179.8 ± 39.5	Ca^{+2}	116.2 ± 17.4	B	0.2 ± 0.1
CE ($dS{\cdot}m^{-1}$)	1.7 ± 0.2	$NO_3{}^-$	9.4 ± 4.5	Mg^{+2}	71.6 ± 9.5	Fe	<0.01
		$SO_4{}^{2-}$	365.1 ± 72.1	Na^+	120.4 ± 31.9	Mn	0.3 ± 0.1
		$PO_4{}^{3-}$	<1.0	K^+	8.4 ± 1.1	Cu	<0.01

2.2. Experimental Treatments

In the lemon trees trial, the experimental treatments tested were:

- FI-Simple: Full irrigation with emitters placed in a single drip line separated by a distance of 1.2 m and with a discharge rate of 3.5 L h^{-1}, and with an irrigation dose that covered the total of the daily water needs (100% estimated crop evapotranspiration (ET_c)).
- SDI-Simple: Similar to FI-Simple, but under a sustained deficit irrigation regime, replacing 50% ET_c. Deficit irrigation began to be applied in February 2018.
- FI-Double: Using 2.2 L h^{-1} drippers, separated by a distance of 1.5 m, placed in 2 drip lines per tree row with water application replacing 100% ET_c.
- SDI-Double: Similar to FI-Double, but with half of the irrigation allocation (50% ET_c). Deficit irrigation began to be applied in February 2018.

The experiment was carried out using a block design with 3 replicates, with 8 trees per treatment and repetition, and the treatments were randomly distributed within each block. The measurement of water potential and growth was carried out in the 4 central trees of each row, while the yield was controlled in 6 trees per row (a total of 18 trees per treatment), discarding the border trees.

In the persimmon trial, the experimental treatments tested were:

- Simple-5: Using 5 drippers per tree with a discharge rate of 3.5 L h^{-1}, separated by a distance of 0.6 m, in a single line.
- Simple-8: Using 8 drippers per tree with a discharge rate of 2.2 L h^{-1}, separated by a distance of 0.4 m, in a single line.
- Double-8: Using a total of 8 drippers per tree with a discharge rate of 2.2 L h^{-1}, separated by a distance of 0.8 m and placed in two pipelines in each row.

The experimental design, in this case, used 6 repetitions per treatment with 7 trees per replicate. Border trees surrounded the experimental ones. In all the treatments, the irrigation scheduled (dose per tree and irrigation events per week) was similar and aimed at replacing 100% ET_c. The measurements of water potential and growth were carried out in the three central trees of each row per replicate and treatment, while the yield was monitored in all the experimental trees of the trial (42 trees per treatment).

In both lemon and persimmon trees, when a single drip line was used, this was placed close to the tree trunk, while when two pipelines were employed, they were installed at a distance of 60 and 80 cm from either side of the tree trunk for persimmon and lemon trees, respectively. In both (lemon and persimmon experiments), the irrigation dose was calculated according to the FAO56 procedure described in Allen et al. [13] with ET_c estimated as the product of ET_o and the crop coefficient (K_c). The reference evapotranspiration values were calculated with the daily time step FAO56 Penman–Monteith equation [13], using the meteorological variables recorded in a weather station located on the same experimental farm (http://www.cebas.csic.es/general_spain/est_meteo.html) (accessed on 21 June 2021). The values for K_c were taken from studies conducted under Mediterranean conditions and reported for persimmon by Intrigliolo et al. [14] and by Carr et al. [15] for lemon trees. The precipitation rates were also recorded in the weather station, and irrigation frequencies varied from 1–2 times per week during winter and early spring to daily irrigation in mid-summer during peak water demand. The same amount of fertilizer was applied to all treatments, as fertilization time and rates were adjusted considering the different emitter rates and numbers employed.

2.3. Experimental Determinations

The soil volume wetted by the different irrigation agronomic designs was estimated after calculating the area in the topsoil wetted by the emitters. This was carried out by measuring the perimeter of the wetted surface by the emitter after one hour of irrigation in all the different agronomic designs explored. The measurements were carried out in 20 emitters per treatment. The wetted surface was calculated assuming a circular shape.

In both trials, tree water status was estimated by measuring the midday stem water potential (Ψs) at an interval of 2–4 weeks for the selected trees. The measurements were carried out using a Scholander type pressure chamber with leaves bagged in aluminized plastic bags at least one hour before the measurement was made. The vegetative tree growth was determined by measuring the trunk perimeter at the beginning and end of the experimental period at the height of 30 cm and 40 cm from the ground for lemon and persimmon, respectively. Tree canopy volume was estimated by measuring, with ranging rods, the crown diameter in two perpendicular directions, and the height, and was calculated according to Hutchinson et al. [16]. In both trials, yield and the number of fruits were determined in all the experimental trees in November 2017, 2018, and 2019 for lemon, and in October 2017 and November 2018 and 2019 in the case of persimmon. In each individual tree, all the fruits were weighed and counted to determine production and average fruit fresh weight.

From each harvest in the different years and for each crop, a sample of fruits was taken from all tree orientations (about 15–20 fruits per treatment and repetition, depending on the year) for the determination of some basic quality parameters, including total soluble solids content, expressed as °Brix, using a digital refractometer (Atago PL-BX/ACID F5; Atago CO., LTD, Tokyo, Japan); and skin color using a Minolta CR-400 colorimeter (Minolta, Ramsey, NY, USA), and expressing the results as a color index ($IC = 1000 \times a/(L \times b)$). In the case of lemon, the titratable acidity (AT) was also determined, expressed as % citric acid using a digital refractometer (ACID F5; Atago CO., LTD, Tokyo, Japan) and the maturity index through the °Brix/TA ratio. In 2017, there are no data available for this parameter due to a failure in the equipment used.

2.4. Statistical Data Analysis

Data from each year were subjected to analysis of variance using an ANOVA (SPSS statistical package, Chicago, IL, USA, 2015). When significant differences at $p < 0.05$ were obtained, the means were separated using Tukey's test. For the case of lemon trees, a factorial two-way ANOVA, considering the irrigation regime and the number of drip lines employed, was carried out.

3. Results

3.1. Environmental Conditions and Water Status

During the experimental period (2017–2019), monthly ET_o remained quite stable every year, with July being the driest month, but the precipitation was very different each year (Table 2). The last experimental season was the rainiest year, with a total precipitation of 781 mm, largely exceeding the historical average for the experimental site. However, this was mainly due to heavy storm episodes occurring in mid-September, with a total of 495 mm in 72 h.

Table 2. Reference evapotranspiration (ET_o) and rainfall during the three experimental seasons. Data reported are monthly and annual cumulative values in mm.

Month	2017		2018		2019	
	ET_o	Rainfall	ET_o	Rainfall	ET_o	Rainfall
January	46.1	40.9	42.3	60	51.9	0.3
February	53.4	3.0	42.7	18	57.9	0.0
March	87.7	83.4	85.7	14.2	75.7	23.8
April	93.4	7.0	102.6	12.2	84.2	146.0
May	74.5	0.0	125.2	4.4	125.4	7.0
June	142.3	0.2	136.01	61.4	149.6	1.0
July	157.4	6.0	162.86	0	158.8	1.2
August	122.6	35.4	130.13	6.8	135.0	24.6
September	97.5	28.8	85.98	25.4	88.8	495.0
October	75.3	10.2	67.14	36.2	69.4	23.0
November	40.1	8.6	42.1	79.4	57.0	12.2
December	39.4	1.4	37.29	6.6	38.0	47.0
Total	1029	225	1060	325	1092	781

In the lemon trial, the deficit irrigation regime (SDI) did not start until the end of the 2017 season, and as a consequence, in 2017, similar irrigation volumes were applied in the FI and SDI regimes (Table 3). However, in 2018 and 2019, trees from the SDI regime received 55% and 52% less water applied than those from the FI regime, respectively. In the persimmon trial, the small variation in water applied between the irrigation treatments was within a range of 10% (Table 3) and was due to the normal field heterogeneity in water application since the intention was to apply the same amount of water in each treatment.

Table 3. Irrigation volumes applied (mm) in each of the experimental treatments and trials.

Treatment	2017	2018	2019
Lemon trial			
FI	188	193	285
SDI	187	107	149
Persimmon trial			
Simple-5	255	342	335
Simple-8	253	370	353
Double-8	264	358	349

In both lemon and persimmon trials, adding an additional drip line increased the wetted area by soil allotted per tree by 112%. The average values were 1.4% and 3.0% for lemon and 4.0% and 8.4% for persimmon, for single and double drip lines, respectively (Table 4). The wetted area relative to the tree crown shaded areas was in general much larger in the young persimmon orchard than in the more adult lemon trees. This was also because of the different tree architectures between the persimmon trees, with more upright shoots than the lemon trees. In the lemon trial, when adding an additional drip line, the wetted area increased from 4.5 to 9.2%. In the persimmon trees irrigated with 8 emitters placed in two drip lines, the soil wetted area relative to the tree shaded area reached values above 100%.

In the lemon trees trial, the tree water status was affected by the deficit irrigation regime, with trees under water restrictions reaching the minimum Ψ_s in July, with values of −2.5 and −2.2 MPa in 2018 and 2019, respectively (Figure 1). The number of drip lines used for applying irrigation did not affect the tree water status.

Table 4. Soil wetted area by emitters in the different experimental treatments in the lemon and persimmon trial. Data are also reported in relation to the soil allotted per tree and the tree crown shaded area. In the lemon trial, the statistical significance for the Drip lines factor included in the ANOVA is also indicated. *** and **, mean significant differences at $p < 0.001$ and $p < 0.01$, respectively. In the persimmon trial, different letters (a or b) indicate significant differences among treatments.

Treatment	Wetted Area (m^2)	Wetted Area by Soil Allotted per Tree (%)	Wetted Area by Crown Shaded Area (%)
	Lemon trial		
Simple	0.6	1.4	4.55
Double	1.3	3.0	9.25
Drip lines	***	***	**
	Persimmon trial		
Simple-5	0.6 [b]	4.0 [b]	47.0 [b]
Simple-8	1.3 [a]	8.4 [a]	85.9 [a]
Double-8	1.3 [a]	8.4 [a]	105.0 [a]

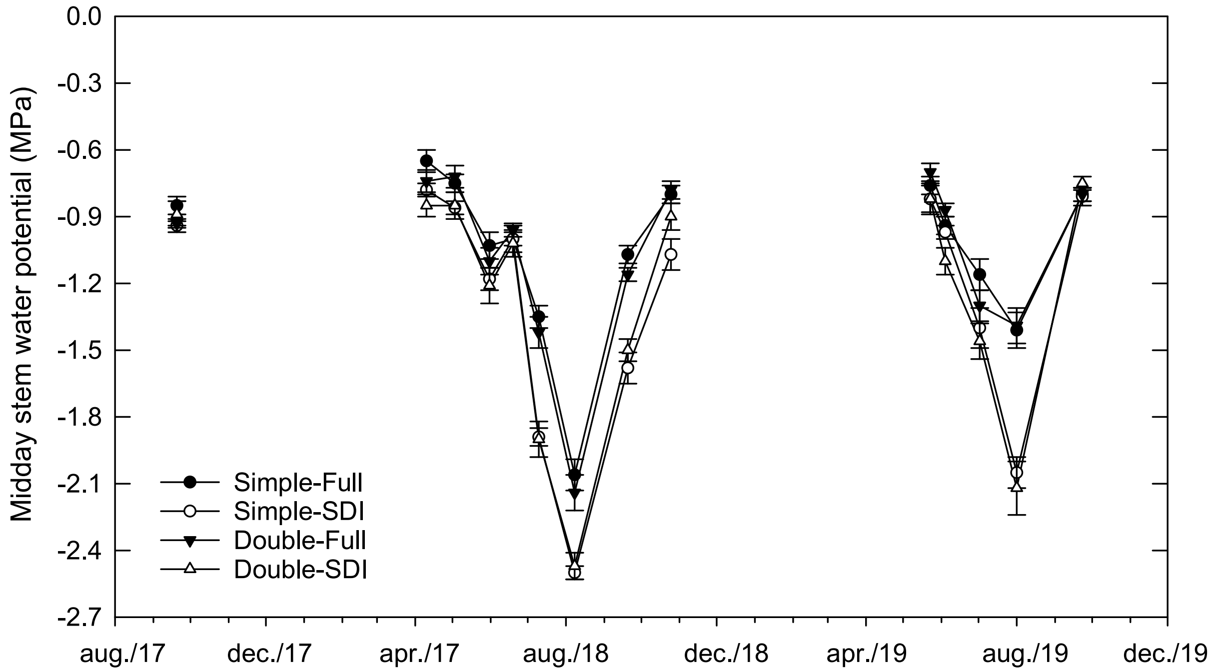

Figure 1. Seasonal variation for midday stem water potential in the different irrigation treatments in the lemon trial. Error bars are the standard error.

In the persimmon trees trial, the effect of the irrigation agronomic design on tree water status was not consistent throughout the experimental period (Figure 2). However, in the last two experimental seasons, in mid-summer, trees irrigated with double lines (Double-4 + 4) had a slightly improved water status (−0.1 to −0.15 MPa less negative) than the other two treatments where drippers were installed in a single drip line.

3.2. *Vegetative Tree Growth*

In the lemon trees, tree growth was only significantly affected by the irrigation regime where SDI reduced both trunk growth rate and the canopy volume at the end of the experiment (Table 5). In the persimmon trial, relative trunk growth increased by 15–18% when the number of emitters per tree increased (Table 5). Canopy volume also increased slightly as the number of drippers increased, although in this case, the differences were not statistically significant at $p < 0.05$.

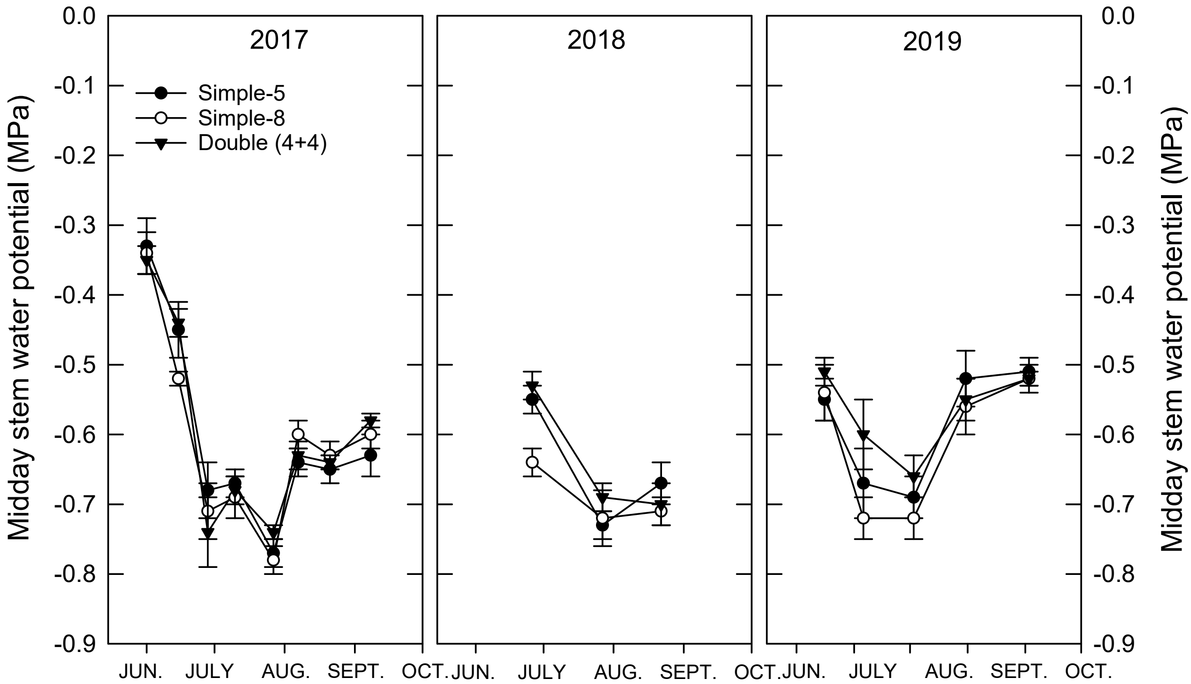

Figure 2. Seasonal variation for midday stem water potential in the different irrigation treatments in the persimmon trial. Error bars are the standard error.

Table 5. Effects of the different irrigation regimes on the relative trunk growth during the entire experimental season and canopy volume measured at the end of the experiment. In the lemon trial, the statistical significance for the different factors included in the ANOVA is also included. ***, *, and n.s., mean significant differences at $p < 0.001$, $p < 0.1$, and non-significant differences between treatments, respectively. In the persimmon trial, different letters indicate significant differences between treatments.

Experimental Treatment	Relative Trunk Growth (2017–2019) %	Canopy Volume 2019 (m^3)
	Lemon trial	
FI-Simple	25.6	19.57
SDI-Simple	20.3	17.87
FI-Double	24.6	21.65
SDI-Double	18.4	19.47
	ANOVA	
Irrigation regime	***	*
Drip Lines	n.s.	n.s.
Irrigation × Drip lines	n.s.	n.s.
	Persimmon trial	
Simple-5	32.1 [b]	1.22 [a]
Simple-8	37.9 [a]	1.42 [a]
Double-8	37.0 [a]	1.30 [a]

3.3. *Yield and Its Components*

In the lemon trial, the number of drip lines only affected the mean fruit weight in the first experimental season, where it increased by an average of 4% using a double line as compared to a single pipeline (Table 6). On the other hand, in the 2018 and 2019 seasons, when deficit irrigation was applied, water restrictions reduced mean fruit weight. As a result, while in 2018 the total yield per tree decreased as mean fruit weight decreased, in 2019, such a decrease in total yield was not observed, as the higher number of fruits per tree in the SDI treatment compensated for the loss in mean fruit weight.

Table 6. Effects of the different irrigation regimes carried out on the lemon trial on yield and its components. The statistical significance for the different factors included in the ANOVA is also included. ***, *, and n.s., mean significant differences at $p < 0.001$, $p < 0.05$, and non-significant differences between treatments, respectively. Within each row, different letters indicate significant differences between treatments.

	Treatments				ANOVA		
	FI-Simple	SDI-Simple	FI-Double	SDI-Double	Irrigation Regime [¥]	Drip Lines	Irrigation × Drip Lines
				Season 2017			
Numbers of fruits per tree	710 [a]	783 [a]	682 [a]	807 [a]		n.s.	
Mean fruit weight (g)	136.5 [b]	140.3 [ab]	144.7 [a]	143.0 [a]		*	
Yield (kg/tree)	96.5 [a]	109.7 [a]	99.3 [a]	115.0 [a]		n.s.	
				Season 2018			
Numbers of fruits per tree	908 [a]	955 [a]	1017 [a]	919 [a]	n.s	n.s.	n.s.
Mean fruit weight (g)	152.2 [a]	116.4 [b]	146.5 [a]	119.8 [b]	***	n.s.	n.s.
Yield (kg/tree)	135.1 [a]	109.9 [b]	147.3 [a]	106.3 [b]	***	n.s.	n.s.
				Season 2019			
Numbers of fruits per tree	755 [b]	869 [a]	757 [b]	842 [a]	***	n.s.	n.s.
Mean fruit weight (g)	146.6 [a]	132.5 [ab]	151.4 [a]	128.9 [b]	***	n.s.	n.s.
Yield (kg/tree)	110.7 [a]	114.7 [a]	114.4 [a]	109.5 [a]	n.s	n.s.	n.s.

[¥] no statistical letters in 2017 for irrigation regime and irrigation × drip lines is because in that year irrigation treatments were not started.

In the persimmon trial in 2017, when the young trees produced their first harvest, no statistically significant differences between treatments were observed (Table 7). In the second experimental season, the Double-8 treatment resulted in a decrease in the number of fruits harvested per tree and a concomitant reduction in total yield, while fruit weight was not affected by the different treatments applied. In the last experimental season, mean fruit weight increased by increasing the number of drippers per tree and pipelines (Double-8), as compared with Simple-5.

Table 7. Effects of the different irrigation regimes on persimmon yield and its components. Different letters indicate significant differences between treatments.

	Simple-5	Simple-8	Double-8
		Season 2017	
Numbers of fruits per tree	16 [a]	17 [a]	17 [a]
Mean fruit weight (g)	249.7 [a]	272.4 [a]	254.5 [a]
Yield (kg/tree)	3.8 [a]	4.2 [a]	4.0 [a]
		Season 2018	
Numbers of fruits per tree	60 [a]	56 [a]	34 [b]
Mean fruit weight (g)	285.4 [a]	306.2 [a]	307.3 [a]
Yield (kg/tree)	16.3 [a]	16.4 [a]	10.2 [b]
		Season 2019	
Numbers of fruits per tree	144 [a]	130 [a]	112 [a]
Mean fruit weight (g)	219.6 [b]	238.5 [ab]	254.5 [a]
Yield (kg/tree)	29.3 [a]	29.3 [a]	25.9 [a]

3.4. Fruit Composition

In the lemon trial, the number of drip lines had a significant effect on fruit composition in every year. (Table 8). In 2017, the juice percentage in lemon fruits increased when two drip lines were installed. In 2018, the TSS and the color index decreased in the double drip lines treatments, while in 2019, the total or titratable acidity decreased, resulting in an overall increase in the maturity index when two drip lines were employed. Deficit irrigation more consistently affected fruit TSS, and the overall effect of the drip lines on fruit composition was not dependent on the irrigation regime.

Table 8. Effects of the different irrigation regimes carried out in the lemon trial on fruit composition. The statistical significance for the different factors included in the ANOVA is also included. ***, **, *, and n.s., mean significant differences at $p < 0.001$, $p < 0.05$, $p < 0.1$, and non-significant differences between treatments, respectively. Within each row, different letters indicate significant differences between treatments.

	Treatments				ANOVA		
	FI-Simple	**SDI-Simple**	**FI-Double**	**SDI-Double**	**Irrigation Regime ¥**	**Drip Lines**	**Irrigation × Drip Lines**
Season 2017							
Juice (%)	23.0 b	23.5 b	29.1 a	26.0 ab	–	***	–
Total soluble solids (°Brix)	7.9 a	8.0 a	7.7 a	8.0 a	–	n.s.	–
Titratable acidity (g/L)	–	–	–	–			
Maturity Index	–	–	–	–			
Color Index	−1.7 a	−1.4 a	−2.3 a	−2.0 a	–	n.s	–
Season 2018							
Juice (%)	31.1 a	28.4 b	30.7 ab	27.4 b	**	n.s.	n.s.
SST (°Brix)	8.6 ab	9.5 a	8.3 b	9.3 a	**	**	n.s.
Titratable acidity (g/L)	7.4 a	7.1 b	7.4 a	7.1 b	**	n.s.	n.s.
Maturity Index	1.2 ab	1.3 a	1.1 b	1.3 a	***	n.s.	n.s.
Color Index	−3.8 a	−5.3 b	−4.2 ab	−7.0 c	***	*	n.s.
Season 2019							
Juice (%)	36.7 a	36.4 a	39.0 a	36.6 a	n.s.	n.s.	n.s.
SST (°Brix)	7.8 ab	8.3 b	7.7 a	8.4 b	***	n.s.	n.s.
Titratable acidity (g/L)	6.1 b	5.7 ab	5.6 a	5.3 a	***	***	n.s.
Maturity Index	1.3 b	1.5 a	1.4 ab	1.6 a	***	***	n.s.
Color Index	−5.9 a	−7.0 b	−6.1 a	−6.6 ab	*	n.s.	n.s.

¥ no statistical letters in 2017 for irrigation regime and irrigation × drip lines is because in that year irrigation treatments were not started.

In the persimmon trial, the general fruit composition was not affected by the irrigation agronomic design, except in 2018 for treatment Simple-8, which increased the TSS concentration relative to the Simple-5 and Double-8 treatments (Table 9). In 2018, fruit from all treatments had a higher color index, indicating a more intense orange color because the harvest was delayed with respect to the other seasons.

Table 9. Effects of the different irrigation regimes carried out in the persimmon trial on fruit composition. Within each row, different letters indicate significant differences between treatments.

	Simple-5	Simple-8	Double-8
	Season 2017		
Total soluble solids (°Brix)	21.3 a	20.8 a	21.1 a
Color Index	1.2 a	0.9 a	1.8 a
	Season 2018		
Total soluble solids (°Brix)	21.2 a	23.1 b	20.9 a
Color Index	6.8 a	7.3 a	6.9 a
	Season 2019		
Total soluble solids (°Brix)	18.1 ab	18.0 a	18.7 b
Color Index	1.5 a	1.9 a	2.2 a

4. Discussion

Within the range of soil wetted areas explored here, both in a still juvenile persimmon orchard and more adult lemon one, the installation of a single drip line seems sufficient to ensure near-optimum tree performance. This could be mainly because having one drip line minimized soil evaporation, considering the relatively low canopy area, particularly for the persimmon trees under testing. This potential decrease in evaporation may have counteracted the potential advantages of increasing the wetted soil volume for reducing deep percolation and lowering the tree hydraulic resistance. In fact, particularly in the lemon trees under the same watering regimes, the type of irrigation agronomic design employed did not affect the seasonal variation in tree water status. However, in the persimmon orchard, which was still at a juvenility stage, even if the percentage of soil wetted area in relation to the tree size was in general high for all treatments, the higher number of drippers per tree increased the percentage of soil wetted area and improved tree water status, perhaps increasing the trunk growth rate. Vegetative growth is, in fact, a tree response that is very sensitive to water status, as tissue growth is highly dependent on the leaf turgor potential [17]. The lack of differences in the tree canopy volume was in part due to the winter pruning, which in the last two experimental seasons buffered the differences created by the irrigation regime imposed. Pruning weights were, in fact, 16–25% heavier in the treatments irrigated with more emitters than in the trees irrigated with only five emitters (results not shown).

In young orchards, an increase in vegetative growth could be particularly beneficial to tree crops such as persimmon, where the yield is determined by the tree size, and an increase in vegetative growth, as that resulting from increasing the wetted area, would lead to higher yields. Longer-term research is required to properly quantify the positive effects of increasing trunk growth on the final tree performance. However, in a mature and well-established orchard, an increase in canopy growth may not be beneficial because smaller trees provide for an easier harvest, pruning, and fruit thinning, with potential cost-savings for producers. In this sense, it should be emphasized that the data reported here for the persimmon trial are of significant interest for a newly planted orchard and cannot be extrapolated to a more mature orchard with larger tree ground covers. Therefore, the data reported here could be used for optimizing irrigation management in newly established plantations, where there could be more uncertainties in terms of responses to irrigation due to a lack of studies under these conditions. More research would be required to determine if initial canopy development during the first years after planting will have an influence on the mid-term productivity. Previous research by Intrigliolo et al. [18] on plum trees has shown that when canopy development is impaired during the first stages of an orchard life cycle because of the application of early deficit irrigation, tree productivity is indeed compromised even if irrigation returns to full dosage.

In the lemon orchard, which was at a more mature stage and already close to the maximum yield potential, the soil wetted area was relatively small, but despite this, tree performance was not improved when increasing the number of drippers employed to double the surface wetted areas. This is in agreement with previous findings obtained under similar experimental conditions [11], which also reported a non-significant effect of installing a second drip line in a nectarine orchard when compared with a single drip line. In the area of study, it is more frequent to find orchards with drip emitters placed in a single drip line located near the tree's trunk. This may respond to the type of soil in this area, usually clay-loam soil, which possesses a high water-holding capacity [5]. Our findings and for our soil conditions, with a loamy-clay-based soil, suggest the convenience for this simpler and convenient irrigation agronomic design. Previous work on apple trees in an orchard with a sandy soil demonstrated the convenience of reducing the number of emitters when deficit irrigation was applied [19]. This should reduce soil evaporation and improve the efficiency of water application. Our results found on lemon trees grown on soil with a heavier texture did not support the previous finding and show that the effect of the number of drippers was independent of the irrigation regime for all the parameters studied.

In the present research, deficit irrigation reduced tree growth. However, in terms of fruit yield, the water savings achieved were much larger and economically important than the yield reduction, which was negligible even in the third year. The higher numbers of fruits per tree in the SDI treatments may respond to the water restrictions applied in the previous season. This is a common response to mild water stress because, in lemon trees, flowering can be induced by the application of a certain degree of water deficit [20]. In the short term, deficit irrigation could clearly increase the water use efficiency, and our study confirms its usefulness as a water-saving strategy, as demonstrated in other citrus tree crops [21] and also in lemon trees [22]. In addition, in the present study, deficit irrigation also modified fruit composition, increasing the maturity index but lowering the color index, which resulted in greener fruits under water restrictions. This indicates that the increase in total soluble solids due to water stress was not a consequence of an early fruit ripening but perhaps a consequence of a concentration effect. The reported effects of deficit irrigation on fruit composition are of interest, particularly for production oriented to exports to overseas markets, where fruit quality is an aspect of increasing interest that is well considered by consumers. The challenge is to attempt to derive threshold values for water stress and its duration in order to be able to modify fruit composition without harnessing final fruit fresh weight at harvest.

In summary, within the range of soil wetted areas explored here in a still juvenile persimmon grove and a more mature lemon orchard, the installation of a single drip line seems to be sufficient to ensure near-optimum tree performance. Installing a single drip line is certainly more advantageous for growers because it results in a less expensive on-farm irrigation deployment and will also allow reducing the plastic employed for the manufacturing of pipes. Longer-term studies in more adult trees are needed to corroborate if the results obtained here with young orchards are also valid and scalable to more mature orchards with a larger canopy size, which could require a higher volume of wetted soil.

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