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Research Article

Effect of wetted soil area on trunk growth, yield, and fruit quality of drip-irrigated sour cherry trees

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Abstract: The effect of wetted soil area on trunk growth, yield, and fruit quality in drip-irrigated Kütahya sour cherry (*Prunus cerasus* L.) trees grafted on mahaleb (*Prunus mahaleb* L.) seedlings was investigated over 3 seasons in a semiarid zone of Central Anatolia, Turkey. Percentages of wetted soil area ranging from 8.8% to 35.6% were obtained by applying 7 treatments consisting of 1 or 2 lateral drip lines per tree row and various dripper numbers per tree. Adequate irrigation was applied to all treatments based on daily evapotranspiration values estimated by the FAO-modified Penman-Monteith equation. The highest yield was generally obtained at percentages of wetted soil area higher than 30%; this was provided by placing 2 lateral lines (1 m apart) per tree row with continual drippers spaced between 0.50 m and 1.00 m. The percentage of wetted soil area did not significantly affect trunk growth and fruit weight in addition to fruit attributes such as redness index of fruit skin color, fruit juice content, soluble solids content, titratable acidity, or pH, in general.

Key words: Drip irrigation, fruit attributes, percentage of wetted soil area, *Prunus cerasus*, trunk growth, yield

Introduction

Sour cherry fruits are an important raw material for the food processing industry, especially in fruit juice production. World sour cherry production is 1,320,000 t, and the 4 largest producers are Turkey, Poland, the Russian Federation, and the United States of America, which provide 14.6%, 14.4%, 12.9%, and 12.1% of world production, respectively (FAO 2009). Sour cherry has been grown in almost all parts of Turkey, but, in particular, it is grown near the central part of the country (Burak et al. 2005), where a semiarid climate is dominant.

Studies on the irrigation of sour cherry are very limited. Since Rzekanowski and Rolbiecki (2000)

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determined a significant and positive relationship between irrigation and yield, they recommended irrigation for better (higher) sour cherry production in Poland. In another study, a good correlation was determined between the fruit developmental period and seasonal transpiration in sour cherry (Bingham et al. 1992). Additionally, a summer water deficit had a negative influence on the growth of wild cherry trees in Italy (Barberis et al. 1999).

Some scientists have reported that the wetted soil volume should be at least one-third to obtain optimum crop yield in arid regions when a drip irrigation method is used. The wetted soil volume can be reduced to 20% in humid regions where rainfall is plentiful and irrigation is mostly supplementary. Wetted soil volume above 50% around the root zone is generally regarded as wasteful for drip-irrigated fruit trees. In order to provide enough wetted volume at root depth for medium-spaced or widely spaced fruit trees, it is suggested that 2 lateral pipe lines per tree row be established in order to obtain a continuous wetted strip; a circular arrangement of drippers around the trees (lateral lines with loops) is also recommended (Baars 1976; Goldberg et al. 1976; Merriam and Keller 1978; Papazafiriou 1980; Nir 1982; Howell et al. 1983; Nakayama and Bucks 1986). However, selection of a suitable number of drippers per tree and application of reasonable irrigation water are reported to be much more important (Keller and Karmeli 1975; Burt and Styles 1994).

Little is known about the relationship between the ratio of wetted soil volume and the growth, yield, and fruit quality of sour cherry trees irrigated by the drip irrigation method. However, studies of other fruit crops are available. Drip irrigation experiments on mature Washington navel orange trees planted in silty clay soils under humid climatic conditions in Uruguay showed a clear trend toward higher yield and larger fruit size when drip irrigation with 2 lateral lines per tree row was used. This resulted in a wetted volume percentage of 35%; meanwhile, 1 lateral line per tree row resulted in a wetted volume percentage of 20% (Petillo et al. 2004). On the other hand, 1, 2, and 3 drip lines per tree row were applied to 13-year-old avocado trees planted in loamy soils in Crete, Greece, where about 800 mm of annual rainfall occurs, and yield was not significantly affected by the applications (Michelakis et al. 1997).

Since percentage of wetted soil area measurements are more practical in drip irrigation applications, the percentage of wetted soil volume should be converted to the percentage of wetted soil area by assuming that the width of the wetted strip is considerably equal in the root zone (Keller and Karmeli 1975).

The aim of this study was to investigate the reasonable percentage of wetted soil area for drip-irrigated sour cherry trees on mahaleb seedling rootstock in clay soils in a semiarid region of Central Anatolia, Turkey. In order to obtain different percentages of wetted soil area, 1 or 2 drip lines per tree were set, and various dripper spacing schemes were considered.

Materials and methods

Experimental site

This study was conducted over 3 consecutive years, from 2002 to 2004, at the sour cherry orchards of the Research and Application Farm of Ankara University's Faculty of Agriculture (39°61′N, 32°40′E; altitude: 1050 m), located in a terrestrial semiarid zone of Central Anatolia. At this farm, long-term annual total precipitation is 411.4 mm and average temperature is 10.0 °C. These annual average values were measured as 376.1 mm and 10.3 °C, respectively, at the farm climatic station during the experimental years.

The soils of the experimental site are clay and are uniform for a depth of 1.5 m. Moreover, their gravimetric moisture contents are 33.3% at field capacity and 21.5% at wilting point, as averages for 120-cm soil depth. The soils have available water holding capacity of 180.4 mm 120 cm^{-1} and a bulk density of 1.28 g cm^{-3}. Soil salt content is low (EC = 0.52 dS m^{-1}, 25 °C) and lime content is 7.9% (Table 1). The soil intake rate was measured as 5.8 mm h^{-1} by double-ring infiltrometers. Soil characteristics and soil moisture content at 120-cm and 150-cm soil depths were taken into consideration for irrigation water application and evapotranspiration measurement, respectively.

The class of irrigation water quality is C_2S_1 (EC = 0.52 dS m^{-1}).

Table 1. Some physical soil characteristics of experimental site.

Profile depth (cm)	Texture class	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})	EC$_e$ × 10^3 (dS m^{-1})	Lime (%)	Available water holding capacity	
							%	mm 30 cm^{-1}
0-30	C	34.1	21.2	1.27	0.44	6.4	12.9	49.1
30-60	C	33.3	21.1	1.28	0.52	8.7	12.2	46.1
60-90	C	33.0	22.3	1.27	0.47	7.1	10.7	40.8
90-120	C	32.7	21.4	1.31	0.63	9.2	11.3	44.4
120-150	C	34.9	21.5	1.20	0.34	5.8	13.4	48.2
0-120	C	33.3	21.5	1.28	0.52	7.9	11.8	180.4

Plant material

Kütahya sour cherry trees (*Prunus cerasus* L.) grafted on mahaleb (*Prunus mahaleb* L.) seedlings were planted with 6 m between rows and 4 m of within-row spacing in 1994. The sour cherry orchard was irrigated by the drip irrigation method from the time of planting to the beginning of the experiment. This method consisted of 2 lateral lines per tree row (1 m apart) with in-line drippers (4 L h^{-1}) spaced at 0.75 m. Other standard orchard management practices such as pruning, nutrition practices, and pesticide applications were carried out regularly each year.

Experimental plot and irrigation treatments

In order to obtain different percentages of wetted soil area by locating 1 and 2 lateral lines per tree row and various dripper numbers per tree, a fixed experiment including 7 treatments and a randomized design with 16 replications was conducted. Each tree in an experimental plot was considered to be one replication (Figure 1).

The irrigation treatments were: I_1 = 1 lateral line per tree row and 2 drippers with 1-m spacing per tree; I_2 = 1 lateral line per tree row with continuous dripper spacing of 1.00 m (4 drippers per tree); I_3 = 1 lateral line per tree row with continuous dripper spacing of 0.50 m (8 drippers per tree); I_4 = 2 lateral lines per tree row and 4 drippers with 1-m spacing per tree; I_5 = 2 lateral lines with 1-m spacing per tree row with continuous dripper spacing of 1 m (8 drippers per tree); I_6 = 2 lateral lines with 1-m spacing per tree row with continuous dripper spacing of 0.75 m (10.7 drippers per tree, lateral layout that had been applied since planting); and I_7 = 2 lateral lines per tree row with continuous dripper spacing of 0.50 m (16 drippers per tree). Lateral spacing in the I_4, I_5, I_6, and I_7 treatments was 1 m. There were 4 tree rows and 68 trees in each experimental plot, and 16 of these were observed (Figure 2).

In this study, pressure-compensating on-line drippers with a discharge rate of 4 L h^{-1} and PE lateral pipe lines with an outer diameter of 16 mm (operational pressure: 2.5 bars) were used. Each lateral pipe line was connected by a 1.27-cm valve to a manifold pipe line.

In order to provide reasonable adaptation among the trees, all irrigation treatments were begun 1 year earlier (2001); however, no tree observations were made, with the exception of trunk diameter measurements. In this year, the percentage of wetted soil area for each treatment was determined by digging in the soil with a shovel and measuring the shape of the wetted soil surface at a soil depth of 20-30 cm (Merriam and Keller 1978). These measurements were taken at 8 locations along the 2 tree rows in each experimental plot in the middle of May, July, and September. The percentage of wetted area was determined by dividing the measured wetted area for a tree into 24 m^2. The wetted soil area for a certain treatment averagely ranged between 8.8% and 35.6% (Table 2).

Irrigation was applied from the beginning of May until the end of September. Applied gross water amounts for each irrigation and irrigation duration were calculated by Eqs. (1) and (2):

$$d_g = \frac{k_c ET_0 P}{E_a} \tag{1}$$

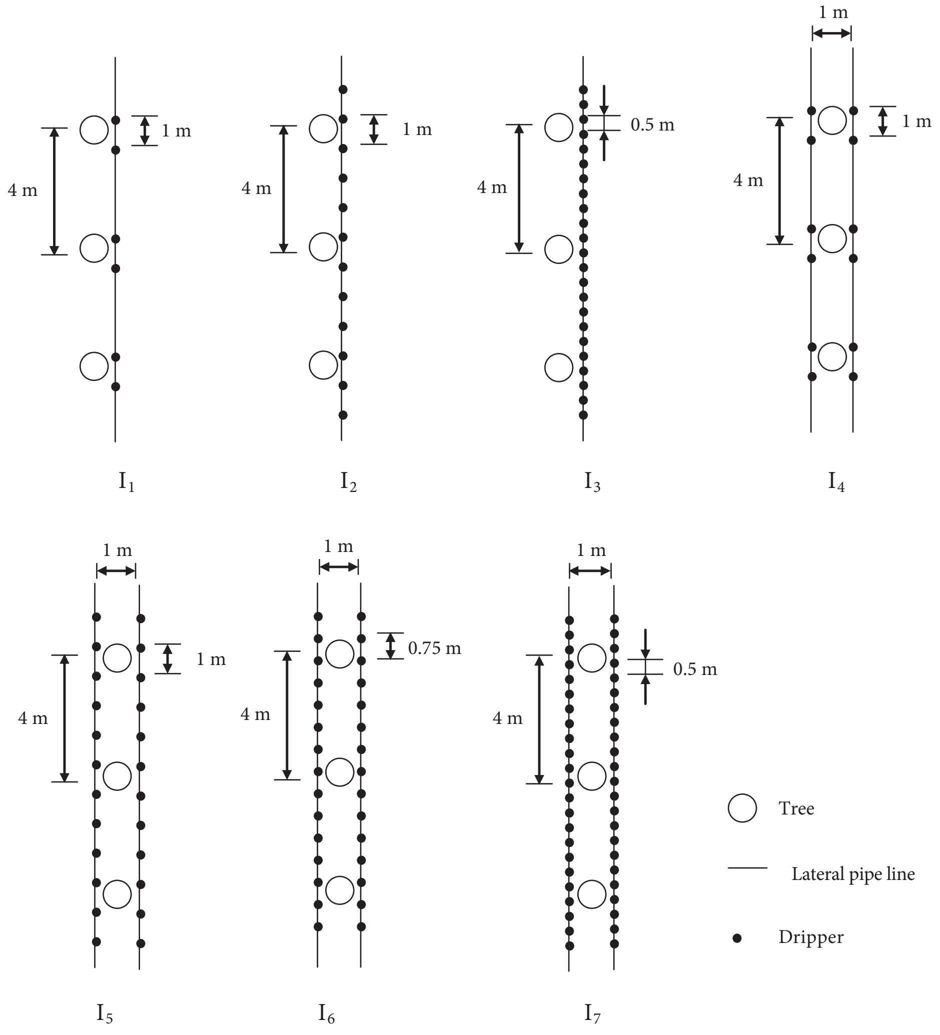

Figure 1. Irrigation treatments.

$$T_a = \frac{10000 d_g}{qN} \qquad (2)$$

where d_g is the amount of applied gross irrigation water (mm), k_c is the crop coefficient, ET_0 is the cumulative reference crop evapotranspiration (mm), P is the percentage of wetted area (Table 2), E_a is water application efficiency, T_a is irrigation duration (h), q is the dripper discharge rate (4 L h^{-1}), and N is dripper number per unit area (number ha^{-1}).

Reference crop evapotranspiration was calculated using the FAO-modified Penman-Monteith equation (Smith 1992; Allen et al. 1998). The necessary climatic data for this equation, such as daily average temperature (°C), relative humidity (%), wind speed at a height of 2 m (m s^{-1}), and sunshine duration (h), were measured at the climatic station located approximately 200 m from the experimental site. The variation in the calculated reference crop evapotranspiration for each season in the experimental years is shown in Figure 3. Crop coefficients for May, June, July, August, and September were 0.60, 0.85, 1.00, 1.00, and 0.90 for the cherry trees, respectively (Doorenbos and Pruitt 1984). Water application efficiency was assumed to be 95% since pressure compensating drippers were used.

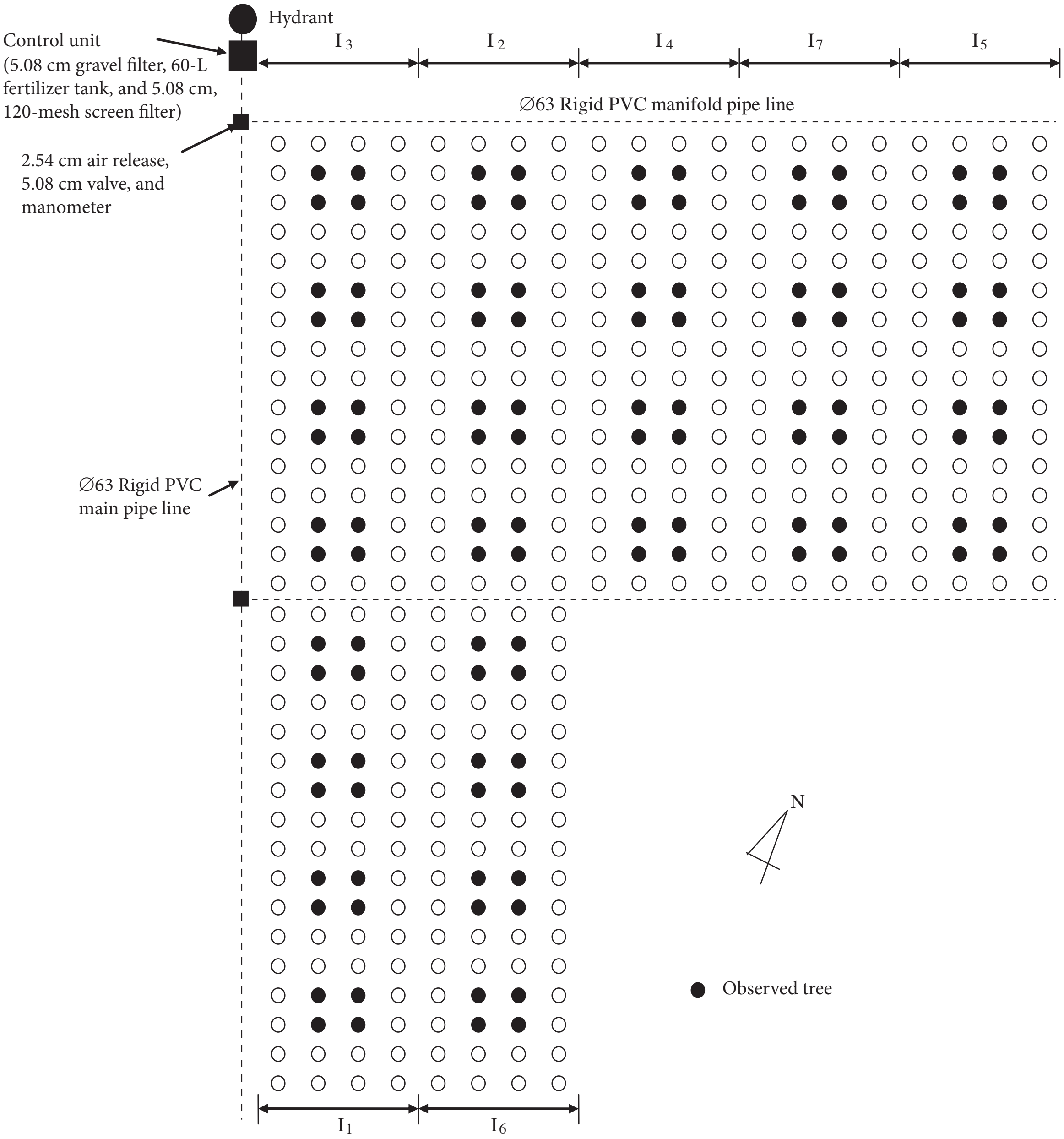

Figure 2. Experimental layout.

In order to obtain water consumption lower than 40% of available water-holding capacity at a 120-cm soil depth, irrigation water was applied in the I_1, I_2, I_3, I_4, I_5, I_6, and I_7 treatments when the cumulative value calculated by Eq. (1) reached nearly 6.4 mm, 10.9 mm, 13.1 mm, 13.6 mm, 22.9 mm, 24.3 mm, and 25.7 mm, respectively. These values were determined by correcting 40% of available water-holding capacity at a 120-cm soil depth with the percentage of wetted soil area. On rainy days, irrigation was reduced according to values calculated by Eq. (1) and rainfall amount.

The moisture around a soil depth of 150 cm was measured based on the gravimetric method at 3 points close to 25 cm from a dripper along a lateral line in each treatment at the beginning of May and the end of September to obtain seasonal evapotranspiration.

Table 2. The percentage of wetted soil area for treatments.

Treatment	The percentage of wetted area (%)
I_1	8.8
I_2	15.1
I_3	18.1
I_4	18.9
I_5	31.7
I_6	33.7
I_7	35.6

The same measurements were also made 2 or 3 times during an irrigation season in order to control moisture content at the beginning of each irrigation season. Seasonal evapotranspiration was determined by the following water balance equation (Howell et al. 1983):

$$ET = SM_b - SM_e + R + D_g - R_f - D_p \tag{3}$$

where ET is the seasonal evapotranspiration (mm), SM_b is the soil moisture content at the beginning of May (mm 150 cm^{-1}), SM_e is the soil moisture content at the end of September (mm 150 cm^{-1}), R is rainfall (mm), D_g is total irrigation water applied (mm), R_f is surface runoff (mm), and D_p is deep percolation (mm). Surface runoff and deep percolation were neglected because the controlled drip irrigation method was applied.

Growth, yield, and fruit quality measurements

Annual growth of trunk cross-section area (TCSA) was determined by measuring trunk circumference at 20 cm above the graft union with a flexible tape during the trees' dormant period each year. The trunk cross-section area was calculated from circumference (TCSA = circumference^2 / 4π).

Sour cherry harvest was performed during the commercial harvest period when the crop was at the red skin color stage of development. The fruits were hand-harvested in mid-July to late July. During the harvest period, yield per tree was recorded and 50 randomly sampled fruits from each tree were evaluated in the laboratory for fruit quality attributes. Average fruit weight, redness index of fruit skin color, fruit juice content, soluble solids content (SSC), titratable acidity (TA), and pH were determined in

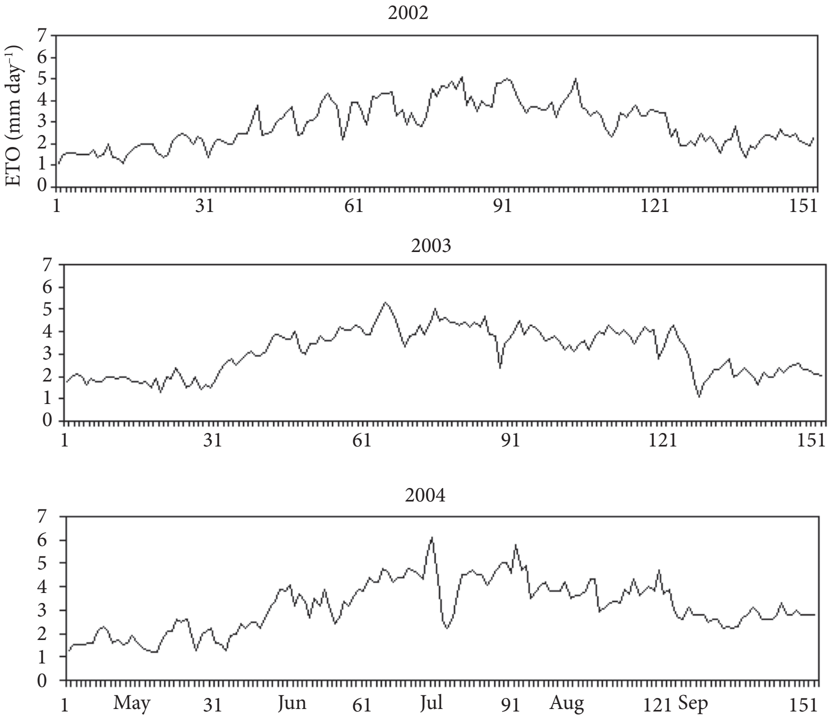

Figure 3. Variation of reference crop evapotranspiration.

these samples. Fruit skin color was measured with a Minolta CR-200 Chroma Meter (Minolta Camera Co., Osaka, Japan) in the CIE L*a* b* color system and then converted to redness index values (McGuire 1992). Fruit juice content (% w/w) was calculated as the ratio of fruit juice to total fruit weight. SSC was digitally measured using an Abbe refractometer. TA (% malic acid) was measured by titrating a 10-mL sample of juice diluted with 20 mL of distilled water with 0.1 N NaOH to an endpoint of pH 8.1. Juice pH was measured with a pH meter.

Statistical analysis

As soils at the experimental site are quite homogeneous in texture, data on growth, yield, and fruit quality were analyzed by the general linear model (GLM) as a repeated experiment with repeated measures over years. Means were separated at the 0.05 level using Duncan's multiple range test (Winer et al. 1991). Statistica 6.0 software (StatSoft Inc., 1984-2001) was used for statistical analysis.

Results

Irrigation and evapotranspiration

The amounts of seasonal irrigation water applied to experimental plots each year were similar (Table 3). These values ranged between 354.7 and 392.1 mm in 2002, between 430.0 and 460.2 mm in 2003, and between 414.1 and 437.2 mm in 2004. The amounts of irrigation water applied were lower in the first year because of the higher rainfall. Irrigation numbers changed between 15 and 77 over the entire research period, and these values were naturally higher in treatments with lower dripper numbers per tree. The seasonal evapotranspiration values determined in 2002 and 2003 were very close to the evapotranspiration calculated with the Penman-Monteith equation and k_c crop coefficients; these values were relatively lower than those calculated in 2004 (Table 3).

Table 3. Results of seasonal irrigation water amount and evapotranspiration.

Year	Irrigation treatment	Rainfall during the season (mm)	Irrigation water applied (mm)	Irrigation number	Evapotranspiration (mm)	
					Estimated by Penman-Monteith equation	Measured
2002	I_1	134.0	392.1	72	442.1	449.3
	I_2		377.2	35		458.8
	I_3		361.7	30		468.3
	I_4		370.5	29		464.7
	I_5		354.7	16		450.5
	I_6		366.1	16		456.8
	I_7		367.1	15		460.8
2003	I_1	56.2	458.0	77	475.2	479.0
	I_2		453.9	46		510.0
	I_3		456.0	38		519.0
	I_4		447.8	34		506.8
	I_5		430.0	20		482.8
	I_6		454.9	20		486.4
	I_7		460.2	18		484.2
2004	I_1	71.6	425.7	72	482.3	395.3
	I_2		427.0	40		419.7
	I_3		414.1	33		430.5
	I_4		432.3	34		415.1
	I_5		434.5	19		434.0
	I_6		428.9	18		432.8
	I_7		437.2	17		443.3

Trunk growth and yield

In this study, irrigation treatment × year interactions were statistically significant for the annual increment of TCSA, fruit yield per tree, and fruit yield efficiency (Table 4).

The annual increment of TCSA was not significantly affected by irrigation treatments in 2002 and 2003. However, there were significant differences among the treatments in 2004. The highest increments (36.1-44.6 cm^2) were obtained from the I_5, I_1, I_4, I_2, I_3,

Table 4. Results of trunk growth and yield components.

Treatment	2002			2003			2004		
	(1) The annual increment of TCSA (cm^2)								
I_1	43.0 ± 2.7[x]	a	A[y]	30.3 ± 2.5	a	B	37.9 ± 3.4	ab	AB
I_2	44.5 ± 2.5	a	A	37.7 ± 3.0	a	A	39.2 ± 3.6	ab	A
I_3	46.4 ± 2.4	a	A	36.4 ± 3.5	a	B	40.0 ± 4.8	ab	AB
I_4	46.2 ± 2.3	a	A	35.0 ± 2.4	a	B	38.3 ± 4.6	ab	AB
I_5	41.0 ± 2.2	a	A	30.8 ± 4.7	a	B	36.1 ± 2.8	ab	AB
I_6	49.5 ± 3.1	a	A	40.5 ± 4.1	a	A	26.9 ± 3.9	b	B
I_7	46.4 ± 1.9	a	A	35.5 ± 3.2	a	B	44.6 ± 2.9	a	AB
	(2) Fruit yield (kg tree^{-1})								
I_1	15.6 ± 1.9	a	C	55.6 ± 4.7	b	A	27.9 ± 2.3	b	B
I_2	14.3 ± 2.0	a	C	74.4 ± 6.3	a	A	26.7 ± 2.2	b	B
I_3	12.8 ± 1.9	a	B	80.6 ± 4.7	a	A	21.4 ± 3.1	b	B
I_4	22.0 ± 2.3	a	C	74.2 ± 6.0	a	A	36.4 ± 2.4	ab	B
I_5	17.3 ± 1.5	a	C	79.8 ± 5.1	a	A	43.2 ± 3.4	a	B
I_6	24.7 ± 2.9	a	C	69.8 ± 5.6	a	A	43.4 ± 3.0	a	B
I_7	23.7 ± 2.5	a	C	79.7 ± 6.1	a	A	47.4 ± 3.6	a	B
	(3) Fruit yield efficiency (kg cm^{-2} TCSA)								
I_1	0.08 ± 0.01	a	B	0.24 ± 0.02	c	A	0.10 ± 0.01	ab	B
I_2	0.07 ± 0.01	a	B	0.30 ± 0.02	abc	A	0.09 ± 0.01	ab	B
I_3	0.05 ± 0.01	a	B	0.30 ± 0.02	abc	A	0.07 ± 0.01	b	B
I_4	0.09 ± 0.01	a	B	0.28 ± 0.02	abc	A	0.12 ± 0.01	ab	B
I_5	0.09 ± 0.01	a	C	0.34 ± 0.02	a	A	0.16 ± 0.01	a	B
I_6	0.11 ± 0.02	a	B	0.26 ± 0.02	bc	A	0.15 ± 0.01	a	B
I_7	0.12 ± 0.01	a	C	0.32 ± 0.02	ab	A	0.16 ± 0.01	a	B

P-values

Source	(1)	(2)	(3)
Treatment (T)	0.498472	0.000254	0.001848
Year (Y)	0.000000	0.000000	0.000000
T × Y	0.013099 [z] **	0.000120 ***	0.000409 ***

[x]: Data presented as mean ± standard error of mean.

[y]: For each parameter, different small letters within a column indicate significant differences among treatments in each year, and different capital letters within a row show significant differences among years in each treatment.

[z]: **, ***: significant at $P \leq 0.01$ and $P \leq 0.001$, respectively.

and I_7 treatments; treatment I_6 had the lowest (26.9 cm^2).

In 2002, yield per tree was not statistically significant among the irrigation treatments. In addition, the yield (12.8-24.7 kg tree^{-1}) in 2002 was significantly lower than in 2003 and 2004. In 2003, the yield was highest; however, there were significant differences among the treatments. The yield per tree was the lowest (55.6 kg tree^{-1}) in treatment I_1, which had 1 lateral line per tree row with 2 drippers per tree and the lowest percentage of wetted area (8.8%). In 2004, treatments I_1, I_2, and I_3 had significantly reduced the yield. Treatments I_2 (15.1%) and I_3 (18.1%) had moderate levels of the percentage of wetted area. In these 3 treatments, the yields were 27.9, 26.7, and 21.4 kg tree^{-1}, respectively. The effect of treatment I_2, which had a moderate level of wetted area (18.9%), 2 lateral lines per tree row, 4 drippers per tree, and a yield of 36.4 kg tree^{-1}, was statistically similar to those of I_1, I_2, and I_3. In 2004, the highest fruit yields were obtained in I_7 (47.4 kg), I_6 (43.4 kg), and I_5 (43.2 kg), which all had 2 lateral lines per tree row and a high percentage of wetted area (35.6%, 33.7%, and 31.7%, respectively) (Table 4). However, the yields in these treatments were statistically similar to that of I_4 (36.4 kg tree^{-1}), which also had 2 lateral lines per tree row with a moderate percentage of wetted area (18.9%). Similar conclusions could be made, in part, for fruit yield efficiency (kg cm^{-2} TCSA area) (Table 4). In 2002, there were no significant differences among irrigation treatments. In 2003, it was significantly higher than in 2002 and 2004. In 2003, the yield efficiency was highest in treatments I_5 (0.34 kg cm^{-2}) and I_7 (0.32 kg cm^{-2}), which had high percentages of wetted area (>30%), and in I_2 (0.30 kg cm^{-2}), I_3 (0.30 kg cm^{-2}), and I_4 (0.28 kg cm^{-2}), which had moderate percentages of wetted area (>15%). However, yield efficiency was significantly reduced (0.26 kg cm^{-2}) in I_6, which had a percentage of wetted area higher than 30%. In 2004, higher yield efficiencies (0.15-0.16 kg cm^{-2}) were obtained in the I_7, I_5, and I_6 treatments, which had 2 lateral lines per tree row and high percentages of wetted area. Yield efficiency was also high in treatments I_1 (0.10 kg cm^{-2}), I_4 (0.12 kg cm^{-2}), and I_2 (0.09 kg cm^{-2}) (Table 4).

Fruit quality

Irrigation treatment × year interactions were statistically significant for all quality parameters investigated in this study (Table 5).

In 2002 and 2004, fruit weight was significantly higher than in 2003. This is likely related to the higher crop load in 2003. In 2002 and 2004, fruit weight ranged between 5.50 and 6.07 g, and between 5.33 and 5.83 g, respectively. There were no significant differences among irrigation treatments in these years. However, in 2003, fruit weight (4.26-4.76 g) was statistically different among irrigation treatments. Treatment I_3 (4.26 g) had the lowest fruit weight. However, the highest fruit weights were obtained in treatments I_6, I_7, I_5, I_1, I_4, and I_2, which had high, moderate, or low levels of percentage of wetted area. The results indicate that there was no relationship between fruit weight and the percentage of wetted soil area.

The redness index was significantly affected by irrigation treatments only in 2002. The highest data were obtained in I_6 (5.4), I_5 (5.3), and I_7 (5.1) treatments, which had high percentages of wetted area. However, the redness index was statistically similar to those of treatments I_1, I_3, and I_4 (4.9). In general, the redness index was significantly higher in 2003 than in 2002 and 2004 for each treatment (Table 5).

The fruit juice content changed from 62.7% to 69.3% among irrigation treatments in 2002, and the differences among treatments were significant. In 2002, treatment I_3 had the lowest juice content (62.7%). In 2003 and 2004, there were no significant differences among the treatments. In treatments I_1, I_2, and I_4, the fruit juice content was not statistically significant among the years. However, in the other treatments, there were significant differences among years, and, in general, juice content increased every other year. It ranged between 69.3% and 72.8% in 2003 and 71.6% and 75.8% in 2004 (Table 5).

As shown in Table 5, in 2002 there was a relationship between SSC and irrigation treatment. The highest percentages (15.6%-15.9%) were obtained from the treatments that had the highest rate of wetted area. No significant relationship was found in 2003 or 2004. SSC ranged from 15.7% to 16.5% in 2003 and the differences among treatments

Table 5. Results for fruit quality parameters.

Treatment	2002			2003			2004		
	(1) Average fruit weight (g)								
I_1	5.52 ± 0.12^x	a	A^y	4.43 ± 0.11	ab	B	5.37 ± 0.14	a	A
I_2	5.86 ± 0.10	a	A	4.36 ± 0.06	ab	B	5.50 ± 0.18	a	A
I_3	5.56 ± 0.09	a	A	4.26 ± 0.06	b	B	5.63 ± 0.12	a	A
I_4	5.50 ± 0.10	a	A	4.40 ± 0.08	ab	B	5.33 ± 0.15	a	A
I_5	6.07 ± 0.13	a	A	4.45 ± 0.09	ab	B	5.83 ± 0.19	a	A
I_6	5.70 ± 0.16	a	A	4.76 ± 0.05	a	B	5.66 ± 0.10	a	A
I_7	5.82 ± 0.08	a	A	4.62 ± 0.06	ab	B	5.63 ± 0.12	a	A
	(2) Redness index of fruit skin color								
I_1	4.9 ± 0.09	ab	B	5.8 ± 0.08	a	A	5.0 ± 0.08	a	B
I_2	4.8 ± 0.14	b	B	5.8 ± 0.13	a	A	4.8 ± 0.11	a	B
I_3	4.9 ± 0.12	ab	B	5.6 ± 0.06	a	A	4.9 ± 0.07	a	B
I_4	4.9 ± 0.17	ab	B	5.7 ± 0.13	a	A	4.9 ± 0.11	a	B
I_5	5.3 ± 0.13	ab	A	5.4 ± 0.10	a	A	5.3 ± 0.13	a	A
I_6	5.4 ± 0.11	a	AB	5.6 ± 0.09	a	A	5.2 ± 0.10	a	B
I_7	5.1 ± 0.10	ab	B	5.7 ± 0.08	a	A	4.9 ± 0.08	a	B
	(3) Fruit juice content (%)								
I_1	68.3 ± 0.43	a	A	69.7 ± 3.41	a	A	71.6 ± 0.90	a	A
I_2	69.3 ± 0.65	a	A	71.8 ± 0.46	a	A	73.2 ± 0.34	a	A
I_3	62.7 ± 2.21	b	B	71.4 ± 0.81	a	A	75.2 ± 0.93	a	A
I_4	68.5 ± 0.88	a	A	71.3 ± 0.53	a	A	72.1 ± 0.82	a	A
I_5	68.9 ± 0.53	a	B	71.6 ± 0.46	a	AB	75.1 ± 0.47	a	A
I_6	68.8 ± 0.46	a	B	69.3 ± 3.77	a	B	75.8 ± 0.56	a	A
I_7	67.3 ± 0.63	a	B	72.8 ± 0.35	a	A	73.6 ± 0.48	a	A
	(4) SSC (%)								
I_1	14.4 ± 0.21	b	B	16.2 ± 0.20	a	A	15.8 ± 0.18	abc	A
I_2	14.5 ± 0.40	b	C	16.4 ± 0.16	a	A	15.4 ± 0.23	bc	B
I_3	15.0 ± 0.30	ab	B	16.5 ± 0.18	a	A	15.9 ± 0.22	abc	A
I_4	15.2 ± 0.30	ab	B	16.2 ± 0.24	a	A	15.6 ± 0.15	abc	AB
I_5	15.9 ± 0.33	a	B	16.1 ± 0.19	a	AB	16.6 ± 0.27	a	A
I_6	15.9 ± 0.21	a	A	15.7 ± 0.25	a	A	16.3 ± 0.22	ab	A
I_7	15.6 ± 0.27	a	AB	16.2 ± 0.18	a	A	15.1 ± 0.18	c	B
	(5) TA (% malic acid)								
I_1	2.47 ± 0.03	ab	B	3.84 ± 0.05	a	A	2.55 ± 0.03	ab	B
I_2	2.29 ± 0.02	b	B	2.50 ± 0.03	c	A	2.42 ± 0.03	b	AB
I_3	2.60 ± 0.05	a	A	2.43 ± 0.03	c	B	2.66 ± 0.03	a	A
I_4	2.39 ± 0.04	b	B	3.13 ± 0.16	b	A	2.50 ± 0.03	ab	B
I_5	2.41 ± 0.03	ab	B	3.71 ± 0.06	a	A	2.48 ± 0.03	b	B
I_6	2.37 ± 0.02	b	C	3.83 ± 0.03	a	A	2.56 ± 0.03	ab	B
I_7	2.47 ± 0.03	ab	B	3.77 ± 0.04	a	A	2.46 ± 0.04	b	B
	(6) pH								
I_1	3.10 ± 0.02	cd	A	2.73 ± 0.02	ab	B	2.77 ± 0.02	ab	B
I_2	3.12 ± 0.01	cd	A	2.68 ± 0.02	abc	B	2.70 ± 0.02	bcd	B
I_3	3.07 ± 0.03	d	A	2.71 ± 0.02	abc	B	2.73 ± 0.02	abcd	B
I_4	3.13 ± 0.01	cd	A	2.67 ± 0.01	bc	B	2.69 ± 0.01	cd	B
I_5	3.32 ± 0.03	b	A	2.75 ± 0.01	a	B	2.78 ± 0.03	a	B
I_6	3.48 ± 0.03	a	A	2.74 ± 0.01	ab	B	2.75 ± 0.01	abc	B
I_7	3.16 ± 0.02	c	A	2.65 ± 0.01	c	B	2.67 ± 0.00	d	B

P-values

Source	(1)	(2)	(3)	(4)	(5)	(6)
Treatment (T)	0.011374	0.249007	0.438764	0.078875	0.000000	0.000000
Year (Y)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
T × Y	0.021273^{z*}	0.000000***	0.027485*	0.000000***	0.000000***	0.000000***

^{x}: Data presented as mean ± standard error of mean.

^{y}: For each parameter, different small letters within a column indicate significant differences among treatments in each year, and different capital letters within the same row show significant differences among years in each treatment.

^{z}*, ***: significant at P ≤ 0.05 and P ≤ 0.001, respectively.

were not significant; however, the differences among treatments were significant in 2004. In this year the lowest SSC (15.1%) was obtained in treatment I_7, which had the highest percentage of wetted area (35.6%).

TA was generally higher in 2003 than in 2002 and 2004. During the 3-year period, statistically similar results in TA were obtained for treatments I_1 and I_2. Treatment I_1, which had the lowest percentage of wetted area (8.8%), and I_2, with 15.1% wetted area, always gave high and low TA values, respectively. During the experimental period, the other treatments showed instability.

The pH values were statistically higher in 2002 (3.07-3.48) than in 2003 (2.65-2.75) and 2004 (2.67-2.78). There were significant differences among treatments in each year. In 2002, the highest pH value (3.48) was obtained in treatment I_6. This treatment also gave high value in other years, whereas treatments I_2 and I_7 had low values in this period. The effect of other treatments on pH was not clear.

Discussion

The results of trunk growth analysis suggest that there is no relationship between trunk growth and the percentage of wetted soil area. This could be due to the mahaleb rootstock onto which the sour cherry trees in the present study were grafted. The major character of mahalebs is their adaptability to calcareous and droughty soils (Webster and Schmidt 1996). According to Shackel et al. (1997), in a combined rootstock-irrigation trial on cherry cultivar Bing there was no apparent rootstock effect on midday stem water potential under fully irrigated conditions; however, when irrigation was reduced, trees on Colt rootstock exhibited a more rapid decline in water status than those on mahaleb. In addition, tree-to-tree differences in water status were large enough to obscure irrigation treatment effects. However, Soing (1989) reported that a reduced irrigation rate retarded vegetative development in cherry. In the present study, the annual increment of TCSA was different among years for each treatment, and it was generally higher in the first and the third year than the second year. This is likely due to the higher crop load in 2003 (Table 4).

In this study, a positive relationship was obtained between the percentage of wetted soil area and yield. Similarly, Rzekanowski and Rolbiecki (2000) reported a significant positive relationship (r^2 = 0.860) between irrigation rate and yield gain from irrigation in sour cherry. Szewczuk and Gudarowska (2001) found that total yield from irrigated trees in sweet cherry cultivars was significantly higher (22%-30%) than in the control. According to these studies, from Rzekanowski and Rolbiecki's (2000) point of view, increase in yield amounted to 20%-25% in apple trees, 20%-28% in sour cherry trees, and 21%-35% in plum trees (Szewczuk and Gudarowska 2001).

The fruit weight results indicate that there was no relationship between fruit weight and the percentage of wetted soil area. Similarly, Szewczuk and Gudarowska (2001) reported that irrigation had no influence on mean fruit weight in sweet cherry.

Our fruit quality results indicate that there was not a permanent relationship between SSC, TA, and pH and the irrigation treatments, which had different percentages of wetted area (8.8%-35.6%). However, it is generally agreed that soluble solids are higher, water content lower, and TA and color more similar in fruits grown under a moisture deficit than in fruits receiving ample water (Proebsting et al. 1984). Bryla et al. (2005) suggested that the method of irrigation had only minor effects on measured fruit quality characters; fruit water content, soluble solids, pH, acidity, and firmness were reported to vary from year to year but were usually quite similar among irrigation treatments in peach. Al-Omran et al. (2010) also reported that the effects of irrigation system and irrigation level on fruit juice, total soluble solids, and fruit thickness of tomato plants were not significant.

In conclusion, the highest yield per tree was generally obtained in treatments I_5, I_6, and I_7, which had 2 lateral lines per tree row and a considerably higher percentage of wetted soil area (31.7%, 33.7%, and 35.6%, respectively). The yield per tree was high when the percentage of wetted soil area was high (>30%). A similar relationship was partly established for yield efficiency. The treatments with various percentages of wetted soil area did not have a significant effect on the annual TCSA growth (Tables 4). In addition, fruit attributes such as redness index of skin color, fruit juice content, SSC, TA, and pH did not change with different irrigation treatments.

A percentage of wetted soil area greater than 30% for sour cherry trees irrigated by the drip method in semiarid regions is better for producing a reasonably high fruit yield. In sour cherry plantations established on clay soils in semiarid regions, 2 lateral lines per tree row, with dripper distances appropriate to provide a continuous wetted strip, should be laid down.

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