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Distribution of Water Loss via Evapotranspiration in a Pistachio Tree Orchard under Drip Irrigation and Non-Irrigation Conditions

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Abstract

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The present study aimed to measure the distribution of water loss via evapotranspiration (ET) in a pistachio tree orchard under drip irrigation and non-irrigation conditions at the experimental orchard of the Pistachio Research Institute, Gaziantep, Turkey. The experimental design consisted of a 10 × 10 m^2 grid system constructed of PVC pipes spaced 2 m apart (horizontally and vertically) that was placed around each tree for the drip irrigation condition (water applied every 7 days) and the non-irrigated condition. Moisture content was measured using the neutron scattering method for both treatments. Water loss via ET was estimated based on the soil water balance method, which included measurement of soil moisture, precipitation, and irrigation. Total water loss via ET under drip irrigation conditions was 518 mm vs 220 mm under non-irrigated conditions. Water loss via ET for the total soil profile and individual layers under non-irrigated conditions was higher at the four outer corners of each 10 × 10 m^2 grid than under irrigated conditions. Moreover, water loss via ET was the highest at the grid system pipes closest to the two laterals under irrigation conditions. In addition, the total percentage of water loss via ET was the highest at the 60–80-cm and 20–40-cm soil layers under drip irrigation and non-irrigation conditions, respectively, and the total percentage of water loss via ET was the lowest at the 40–60-cm and 0–20-cm soil layers under drip irrigation and non-irrigation conditions, respectively. Lastly, it could be considered that root density increased as water loss via ET increased.

Keywords: drip irrigation; evapotranspiration; pistachio; root; water loss

The origin of the pistachio tree is contentious. Some researchers suggest its origin is Anatolia and western Asia, where it remains wild (Vargas 1998), whereas others suggest it originated in Lebanon, Palestine, Iraq, southern Europe, and the desert countries of Asia and Africa (Hendricks & Ferguson 1995). Pistachio is one of the most important crops in Turkey. The most recent agricultural survey in Turkey has shown that pistachio is cultivated in 44 cities, but that its cultivation occurs primarily in southeastern Anatolia (Babadoğan 2010).

Pistachio grows primarily under non-irrigated conditions and although pistachio trees are irrigated in Turkey, the optimal irrigation scheme remains unknown. It is also thought that pistachio does not require irrigation or such cultural practices as fertilization, cultivation, and grafting, and that natural precipitation is sufficient to grow pistachio in Turkey with high yields (Özmen 2002). The first study on pistachio irrigation in Turkey was conducted at the Institute of Pistachio Research, Gaziantep, Turkey, in

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1973 (Bilgen 1973). To date, the literature contains only a few studies on pistachio irrigation.

The pistachio tree is known to be drought tolerant (Goldhemer *et al.* 1984; Kanber *et al.* 1990); however, for optimal yield performance irrigation is required (Goldhamer 1995). Monastra *et al.* (1997) reported irrigating pistachio improves trunk development, and increases the number and size of inflorescences. In addition, Kanber *et al.* (1993) and Goldhamer *et al.* (1985) reported that pistachio yield increased in response to irrigation, and Özmen (2002) observed that pistachio yield increased by 67% under irrigation conditions, as compared to non-irrigation conditions in southeast Anatolia. In the San Joaquin Valley of California midsummer water loss via evapotranspiration (ET) (June–August) was 7.5 mm on average for clean cultivated mature pistachio trees (Goldhamer *et al.* 1985). In southeastern Turkey the ET rate is the highest in August (205 mm/month and 6.6 mm/day) (Kanber *et al.* 1986).

Hakgören (1993) reported that application of fertilizers via irrigation systems (fertigation) can effectively deliver nutrients to the root zone, which contains the highest concentration of roots. Application of liquid or residue solid fertilizers via fertigation facilitates both the optimal concentration of nutrients and water storage in the root zone. This practice prevents secondary soil salinization and ground water pollution (Darwish 1995).

Goldhamer *et al.* (1989) reported that the volumetric soil water content in the top 15 cm of soil was 3.7% on average under drip irrigation conditions vs 10.6% under low-volume sprinkler (LVS) conditions. The highest soil water level in the zone of application in the drip irrigation plot was at a depth of 60 cm. The presence of roots in the upper part of the soil profile was clearly observed under LVS conditions, whereas no roots were observed above the depth of 40 cm under buried drip irrigation conditions. Clearly, root geometry was positively affected by subsurface irrigation, which kept the upper profile zone dry, eliminating root development in that area of high inoculums.

Kanber *et al.* (1993) reported that root activity under flood irrigation treatment every 20 days was lower at shallower soil depth, as compared to flood irrigation treatment every 30 days. On the other hand, Spiegel-Roy *et al.* (1977) observed that root distribution in pistachio trees was uniform at the soil depths ≤ 240 cm. Root uptake of nitrogen, phosphorus, and potassium from soil is not associated with root growth, although "on"-year trees exhibit less root growth than "off"-year trees during nut fill. The rooting habit of the pistachio tree is characterized as phreatophyte, with an extensive root system that facilitates mining of soil at a considerable depth; as such, pistachio is quite drought resistant (Hendricks & Ferguson 1995).

The roots of pistachio trees that have been grown under non-irrigation conditions grow deeper and further from the trunk than the roots of trees that have been irrigated (Kaşka 1990); as such, we think research is necessary to determine if irrigation of pistachio tress can increase root density at depths and distances closer to the trunk. Goldhamer *et al.* (1989) reported that the root density of pistachio trees could be increased via irrigation. As such, the aim of the present study was to measure the distribution of water loss via ET in a pistachio tree orchard under drip irrigation and non-irrigation conditions.

MATERIAL AND METHODS

Field work was conducted in a region between Mediterranean and desert climates – a typical transient zone – at the experimental orchard of the Pistachio Research Institute, Gaziantep, Turkey. The experimental orchard had an area of approximately 3.0 ha and was located 36°56'N, 37°28'E at an altitude of 705 m. The experimental orchard soil is placed in the sub-basin of the Gaziantep-Birecik. This basin soil is a soil series of the Karacaveran – a Calcic Vertisol. Widely distributed soils developed on caliches (calcretes) were represented in the soil profile. The topography of the orchard was non-problematic. All analyses were performed via Richards' (1954) methods and the results are shown in Table 1.

A 10 × 10-m planting distance was employed for the Uzun variety of pistachio trees (*Pistacia vera* L.) used in this study. This type of pistachio is widely grown in Turkey and the roots can grow 5–6 m from the trunk under non-irrigation conditions in southeastern Turkey (Tekin *et al.* 2001). The experimental orchard was 28 years old and in the off year in 2001, when the study was conducted.

Irrigation water was supplied by two wells in the orchard that were approximately 220 m deep. The electrical conductivity (EC) of the water in the two wells was 0.25–0.75 dS/m, and the sodium absorption ratio (SAR) was 0–10 (C_2S_1 class). A drip irrigation system was used to supply irrigation water. The ir-

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Table 1. Physical and chemical characteristics of the experimental orchard

Soil depth (cm)	Texture	FC	PWP	Bulk density (g/cm^3)	pH	Salt content	Lime	Clay	Sand	Silt
		(g/g)				(%)				
0–30	C	37.71	21.13	1.33	7.34	0.116	17.23	73.32	4.13	22.54
30–60	C	37.69	21.08	1.15	7.43	0.109	17.24	71.58	2.81	26.27
60–90	C	38.05	21.22	1.33	7.54	0.098	18.31	76.21	3.19	20.59
90–120	C	37.30	21.26	1.29	7.58	0.095	19.92	77.32	2.93	19.76
120–150	C	34.78	21.02	1.39	7.68	0.195	23.75	75.93	4.33	20.27

C – clay; FC – field capacity; PWP – permanent wilting point

rigation system consisted of a pipe network and a control unit, including a pump, injection equipment, filters, and flow and pressure measuring devices. Well water passed through a vortex filter and was mixed with fertilizer, including nitrogen, phosphorus, and potassium, in the fertigation system for the irrigated treatment.

The amount of irrigation water applied to the experimental plots was calculated using the following equation (Kanber 1999):

$$IR = K_{pc} \times E_{pan} \times C \quad (1)$$

where:

IR – amount of irrigation water

E_{pan} – cumulative free surface water evaporation for the 7-day irrigation interval

K_{pc} – coefficient relevant to crop and pan type (0.90 was used in this study)

C – wetting percentage (30% was used)

To control the wetting percentage, the wetted area was measured after each irrigation application. An evaporation pan was placed on the bare soil at the centre of the experimental orchard.

The study included two groups of trees: drip irrigated and non-irrigated. The pistachio trees in both treatment conditions had similar canopy properties. For the irrigation treatment the irrigation interval was 1 week; nitrogen fertilizer was injected at the concentration of 20 ppm at 1-week intervals, and 15 ppm and 10 ppm of phosphorus and potassium fertilizer, respectively, were injected at 2-week intervals. For both experimental treatments 500 g of N, 600 g of P_2O_5, and 400 g of K_2O were applied to the projection of each tree crown in February 2001. The experiment was conducted using a split-split block design with 2 replications. Each irrigated and non-irrigated plot included 8–10 trees, and was 813 m^2.

The moisture content of the soil profile in each plot was measured 1 day before and 1 day after irrigation in both treatments. The moisture level was also measured before the start of irrigation and at the end of the growing period, which corresponded to leaf freshening and leaf shading times, respectively.

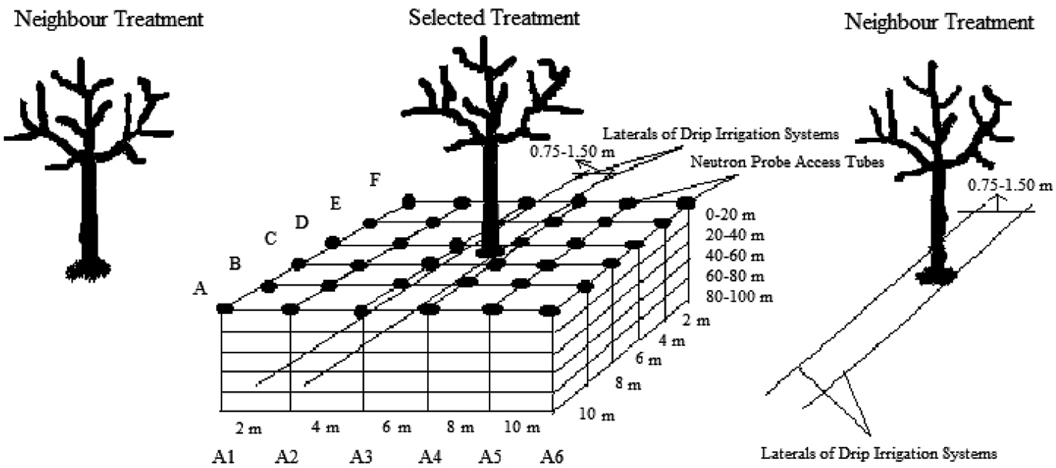

Figure 1. Schematic view of the grid system around each tree

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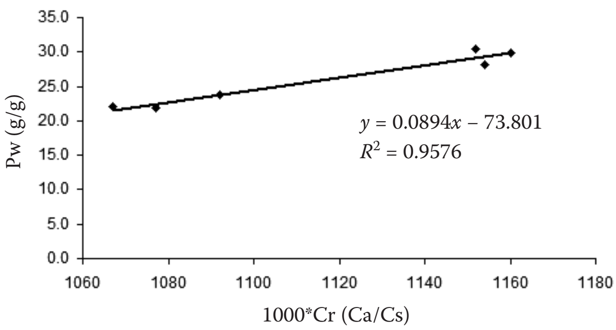

Figure 2. Neutron calibration curve for the pistachio orchard

Measurements were performed using neutron scattering every 20 cm and gravimetric methods every 30 cm of soil depth to maximum depth of 120 cm.

Water loss via ET was estimated in an area assigned to a tree before and after each irrigation event in the irrigated and the non-irrigated treatments. As such, a 10 × 10-m^2 grid system was constructed of 5-cm × 120-cm PVC pipes spaced 2 m apart (horizontally and vertically) around each tree for both the drip irrigation and non-irrigated conditions (Figure 1). In order to measure soil moisture at the grid corners, a neutron moisture gauge was used (Kanber 1997), and readings were obtained at soil depth intervals of 0–20, 20–40, 40–60, 60–80, and 80–100 cm from 36 access tubes of each grid. Neutron moisture gauge measurement count ratios and the ratio of actual to standard counts were converted to volumetric water content using a calibration curve obtained using the method given by IAEA (2002) (Figure 2). As such, gauge readings and samples of gravimetric soil were obtained at the same time from the five different soil layers in each of the irrigated and non-irrigated experimental plots.

The water balance approach was used to calculate water loss via ET in each experimental plot using the following equation (Kanber 1997):

$$ET = IR + P + C_p - D_p \pm R_f \pm \Delta S \qquad (2)$$

where:

IR – application of irrigation water to the plots (mm)

P – rainfall (mm)

C_p – capillary rise (mm)

D_p – deep percolation (mm)

R_f – runoff into or out of the plots (mm)

ΔS – moisture content change (final minus initial)

Irrigation water, rainfall, and moisture content were measured, and other components were assumed to be zero in the irrigation treatment due to the lack of rainfall (Kanber *et al.* 1993).

RESULTS AND DISCUSSION

Irrigation and fertilizer. The irrigation period began on May 5, 2001 and ended at harvest – September 10, 2001. The total amount of water applied in the irrigated treatment plots was 272 mm and total E_{pan} was 1028 mm during the irrigation period. More nitrogen was applied in the irrigated treatment than in the non-irrigated treatment. Some of the findings regarding the amount of irrigation and fertilizer applied in each treatment are shown in Table 2.

Evapotranspiration. Water loss via ET under irrigated and non-irrigated conditions was calculated using the water budget method (Table 3). Total water losses via ET under irrigated and non-irrigated conditions were 518 mm and 220 mm, respectively. Water loss via ET for the non-irrigated treatment was by 58% lower than for the irrigated treatment. Goldhamer *et al.* (1984) reported that water loss via ET in pistachio was 1017 mm during one irrigation season in California. Moreover, Kanber *et al.* (1993) reported that water loss via ET in pistachio was 803 mm during one irrigation season in the region of southeastern Anatolia in Turkey. Differences in the reported levels of water loss via ET could be attributed to differences in soil and climate characteristics, and the irrigation methods used.

Irrigated and non-irrigated plots. Water loss via ET from each soil layer and the total soil profile at the grid corners for both treatments are shown in Figures 3–8. For the irrigated treatment water, loss

Table 2. Amount of N, P, and K fertilizer applied in both treatments

Treatments	E_{pan} (mm)	IR (mm)	N (g/m^2)	Plot area ($g/813\ m^2$)	P (g/m^2)	Plot area ($g/813\ m^2$)	K (g/m^2)	Plot area ($g/813\ m^2$)
Irrigated	1028	272	1.63	1326.4	0.44	355.7	0.29	237.2
Non-irrigated	–	0.0	–	500.0*	–	600.0*	–	400.0*

E_{pan} – cumulative free surface water evaporation for the 7-day irrigation interval; IR – irrigation water; *per tree

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Table 3. Seasonal evapotranspiration (ET, in mm) (April 20, 2001–November 7, 2001)

Treatments	ΔS	P	IR	ET
Irrigated	161	85	272	518
Non-irrigated	135	85	0.0	220*

ΔS – moisture content change; P – rainfall; IR – irrigation water; *under dry conditions

via ET was considered the total water lost following four applications of irrigation vs the entire irrigation season for the non-irrigated treatment.

Findings for the total soil profile and each soil layer show that water loss via ET was higher under irrigated conditions than under non-irrigated conditions at each grid corner. The findings for the irrigated treatment show that water loss via ET was higher the closest to both laterals, between lines A–B, B–C, and E–F, whereas water loss via ET was lower the closest to the tree trunk and between line C–D (Figure 3–8). Water loss via ET was slightly higher (18.8%) in the irrigated treatment at the 0–20-cm soil layer, as compared to the non-irrigation treatment. On the other hand, water loss via ET was the highest at the

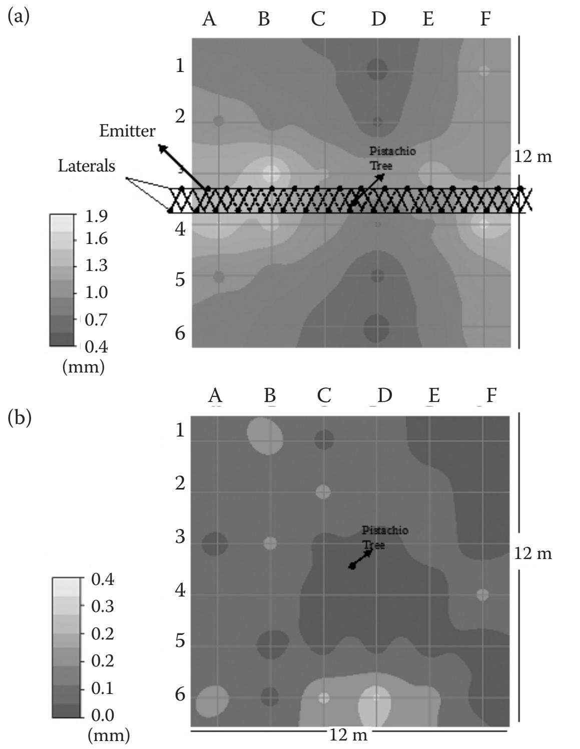

Figure 4. Water loss via evapotranspiration at the 0–20-cm soil layer at the grid corners for the irrigated (a) and non-irrigated (b) treatments

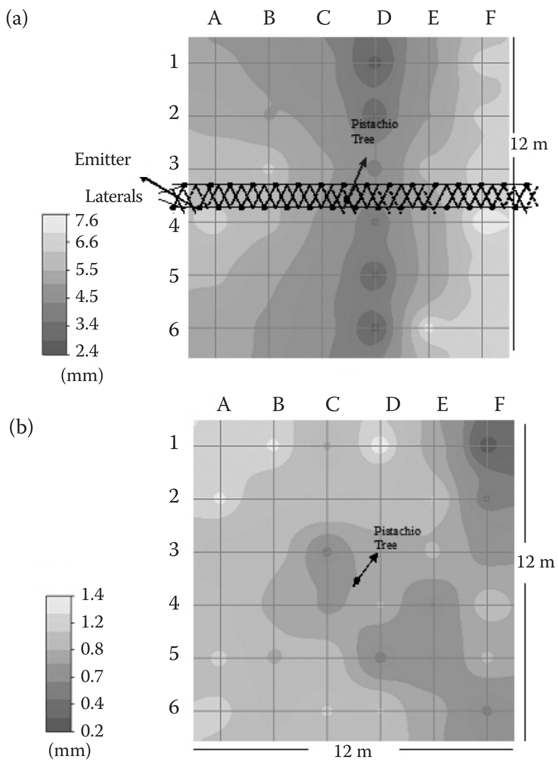

Figure 3. Water loss via evapotranspiration from the total soil profile (0–100 cm) at the grid corners for the irrigated (a) and non-irrigated (b) treatments

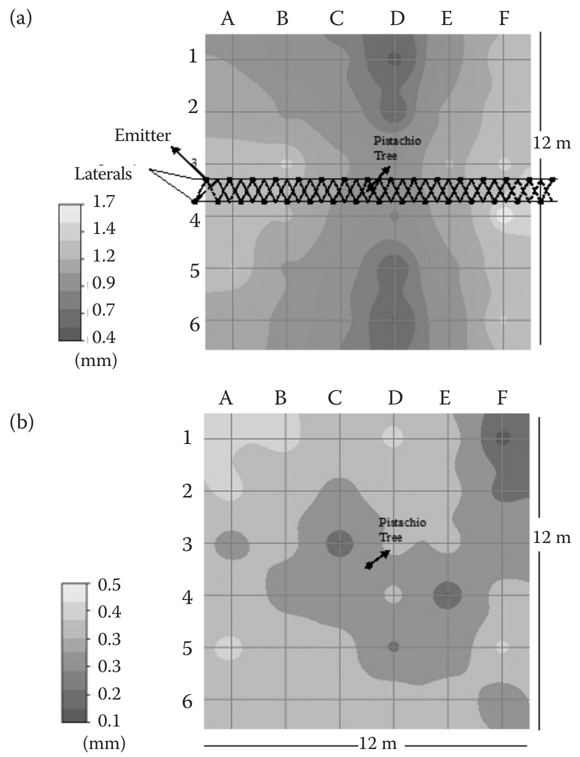

Figure 5. Water loss via evapotranspiration at the 20–40-cm soil layer at the grid corners for the irrigated (a) and non-irrigated (b) treatments

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60–80-cm soil layer at line F, as compared to the total soil profile. The high level of water loss via ET at the laterals (e.g. line F) in the irrigated treatment might have been due to the movement of soil water from irrigated plots to non-irrigated plots along the matric soil water potential gradients; however, the high level of water loss via ET for this line and the other lines farther from the trees at different layers might have been due to higher root activity. Thus, we think that the lower level of water loss via ET observed nearest to the tree trunks on line D was most probably due to lower root activity.

Water loss via ET for the total soil profile and each soil layer in the non-irrigated plots was higher at the four outer corners of each grid; water loss via ET was the lowest at the 0–20-cm soil layer and the highest at the 20–40-cm soil layer. As observed in the irrigated plots, water loss via ET was very low at all soil layers closest to the tree trunks. The lowest level of water loss via ET (0) was observed at the 0–20-cm soil layer at lines C and D, which were closest to the trees. For the non-irrigated treatment water loss via ET was generally the lowest at line F, which is in contrast to the irrigated treatment. Most

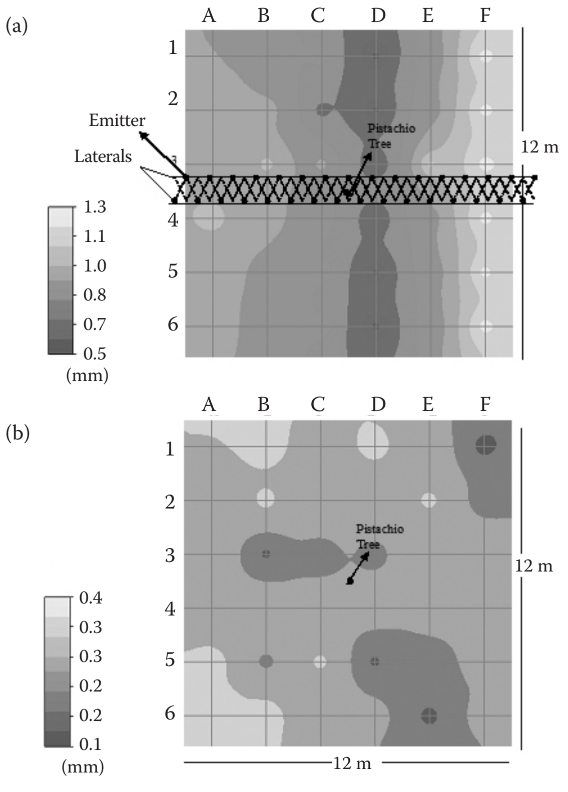

Figure 6. Water loss via evapotranspiration at the 40–60 cm soil layer at the grid corners for the irrigated (a) and non-irrigated (b) treatments

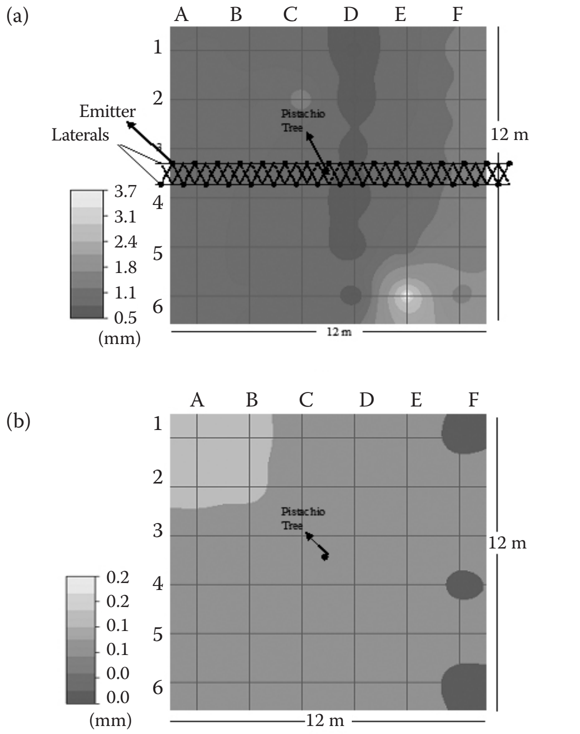

Figure 7. Water loss via evapotranspiration at the 60–80 cm soil layer at the grid corners for the irrigated (a) and non-irrigated (b) treatments

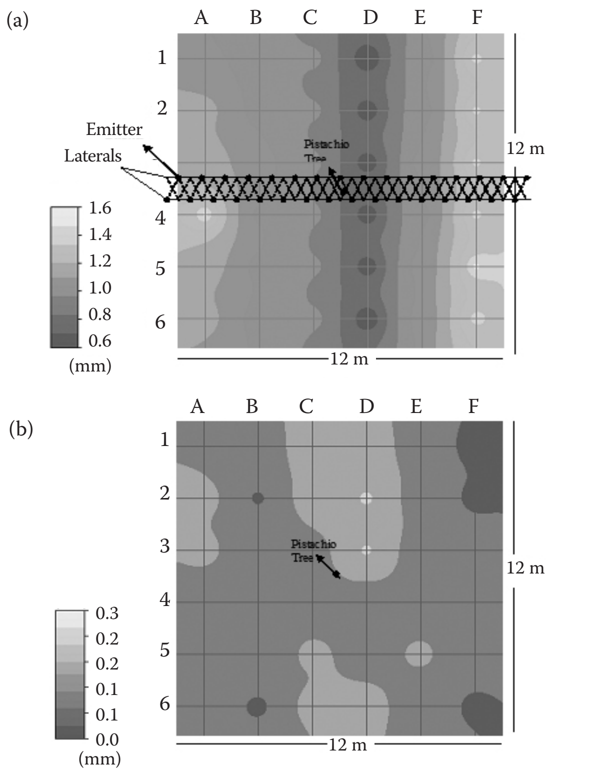

Figure 8. Water loss via evapotranspiration at the 80–100 cm soil layer at the grid corners for the irrigated (a) and non-irrigated (b) treatments

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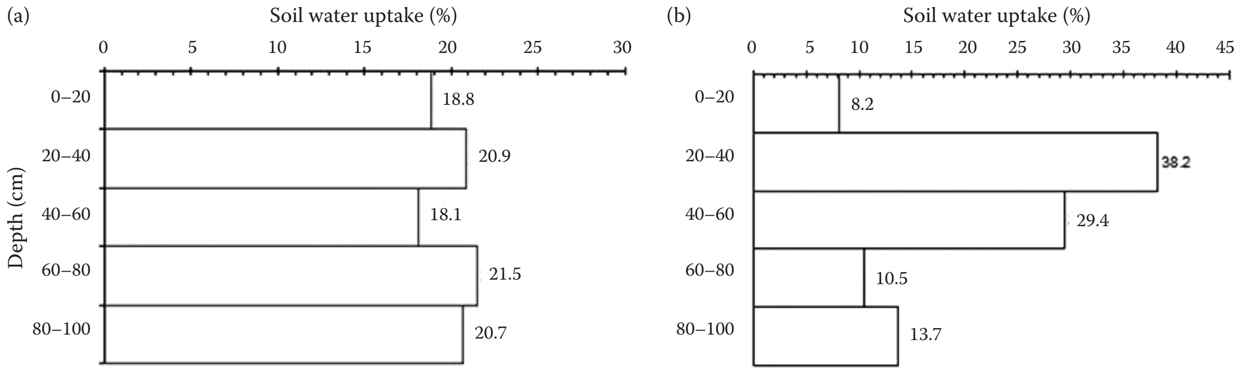

Figure 9. Water loss via evapotranspiration (%) for the total soil profile at the grid corners for the irrigated (a) and non-irrigated (b) treatments

probably the four outer corners of the grid in each non-irrigated plot were affected by the matric soil water potential gradients of the irrigated treatment plots on either side. As such, it can be assumed that water loss via ET increased due to an increase in root density. Kaşka (1990) also reported that root density in pistachio trees under non-irrigated conditions increased along with the distance from the trunk, which we think is what occurred in experimental pistachio orchard of the present study, as the trees had been cultivated under non-irrigation conditions until 1998.

The total percentage of water loss via ET for the irrigated treatment was maximum and minimum at the 60–80-cm and 40–60-cm soil layers, respectively (Figure 9a), vs the 20–40-cm and 0–20-cm soil layers, respectively, for the non-irrigated treatment (Figure 9b). Thus, root density was the highest at the soil layer in which water loss via ET was the highest. Levin *et al.* (1972) reported that water loss via ET under irrigation conditions increased as soil depth decreased. Moreover, Goldhamer *et al.* (1989) observed that the highest soil water level in their drip irrigation plot was at a depth of 60 cm, i.e. the zone of application, whereas no roots were observed above 40 cm.

CONCLUSION

In this study, the distribution of water loss via ET in a pistachio tree orchard under drip irrigation and non-irrigation conditions was measured. The present findings show that water loss via ET of the total soil profile and each soil layer was higher under irrigated conditions than under non-irrigated conditions at each grid corner. Furthermore, water loss via ET was higher the closest to both laterals under irrigation conditions, and was lower the closest to the tree trunks under non-irrigation conditions. The total percentage of water loss via ET was lower in the non-irrigated treatment at the upper soil layer (0–20-cm) of the soil profile than in the irrigated treatment. Based on these findings, we conclude that root activity and density were higher where water loss via ET was higher under both irrigated and non-irrigated conditions. Moreover, we think the present findings can be used to improve cultural practices at new as well as already existing pistachio orchard plantations.

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