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Evaluation of financial efficiency of drip-irrigation of red pepper based on evapotranspiration calculated using an iterative soil water-budget approach

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ABSTRACT

This study examined the effects of different water management strategies on red pepper (*Capsicum annuum* L. *cv. Kapija*) crop evapotranspiration (ETc), yield and fruit quality. The study was conducted in the Bafra Plains in Northern Turkey over a two-year period (2010–2011). Three irrigation treatments [1 full (S1) and 2 deficit (70%-S2, 40%-S3)] and 1 rainfed treatment (S4) were applied. Soil water budget calculations used a detailed, iterative approach to identify ETc of wetted and vegetation-covered parts of the field (ETc_{rz}), i.e. the "root zone", and a new equation was used to convert ETc_{rz} values to ETc values for the entire plot in order to improve the accuracy of ETc measurements for drip-irrigated crops. ETc values of the treatments varied between 294.0–472.0 mm in 2010 and 163.0–508.0 mm in 2011. The maximum yield was obtained with the S1 treatment (42.43 t ha^{-1}). Statistical analysis showed the S1 treatment to have a significantly higher yield than all other treatments, while the difference in the yields of the S3 and S4 treatments was not statistically significant. Calculations of water use efficiency (WUE), net economic income (NIC) and financial efficiency (FE) indicated that under rainfed conditions, despite the high WUE (11.9 kg m^{-3}), NIC from red pepper cultivation would be below that of production costs. FE analysis indicated the most profitable strategy for red pepper cultivation to be full irrigation (S1), which had an FE value of 1.6 (\$$m^{-3}$), whereas both the S3 and S4 treatments had negative FE values ranging between −1.2 and −2.1 (\$ m^{-3}).

1. Introduction

When compared to field crops, horticultural products tend to produce greater economic output per unit of crop evapotranspiration (ETc), which has led to a general shifting of irrigated land from field crops to horticultural crops, especially in areas where water is scarce (Fereres et al., 2003). Red pepper is a high-value horticultural crop that can be consumed directly or after processing (Karaagac and Balkaya, 2010). In Turkey, there has been an increase in annual red pepper production, which, in 2016, reached 957,030 tons, produced on 32,558 ha of irrigated land, with 8.81% of total production taking place in the Black-Sea province of Samsun (TUIK, 2015). Previous research has shown that in areas receiving most of their precipitation in winter, irrigation is an important factor in terms of red pepper yield and quality. Gencoglan et al. (2006) and Sezen et al. (2011, 2015) stated that irrigation scheduling throughout the growing season is crucial for realizing higher red pepper yields. This is supported by studies such as Doorenbos and Kassam (1979), Alvino et al. (1994) and Dimitrov and Ovtcharrova (1995). Kuşçu et al. (2016), Sezen et al. (2015) and Dagdelen et al. (2004) found that water stress decreased both yield and quality of red pepper. For maximum red pepper yield, Xie et al. (1999) and Mahajan et al. (2007) suggested drip irrigation instead of surface irrigation methods. Within the framework of a national policy of water conservation for environmental sustainability and increasing yield and quality for agricultural profitability, government support for pressurized systems has helped to bring about the widespread use of drip irrigation for red pepper production in Turkey.

Drip irrigation results in water savings in two ways: first, less water is lost as a result of the completely closed pipeline system; and second, only a part of the soil surface is wetted, whereas the rest remains dry − which is especially significant for crops with wide row spacing. According to Keller and Bliesner (1990), while wetting percentages (Pw) in general may vary within a set range, crops with wide row spacing require a Pw of $^{<}1$ in order to conserve water. When selecting Pw values during the planning and operation of drip irrigation systems, soil physical properties, dripper flow and space, crop type and

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phenological stage, all need to be taken into consideration (Keller and Karmeli, 1974). Soil surface evaporation (E) is a significant component of crop water-consumption that may be limited by allowing some areas to remain dry through partial wetting and letting vegetation provide shading of wet soil surfaces. (Bonachela et al., 2001; Luo et al., 2011; Fereres, 1981; Allen et al., 1998; Heerema et al., 2008).

Bonachela et al. (2001) reported that E may be estimated from a uniformly wetted soil surface using semi-empirical equations (Philip, 1957; Black et al., 1969; Ritchie, 1972; Ritchie and Johnson, 1990; Bonachela et al., 1999). Allen et al. (1998) suggest using a soil-evaporation coefficient (K_e) equal to the maximum-crop coefficient (K_c) immediately after wetting events. Although the literature includes various methods for the joint estimation of E and transpiration (T), with partially wetted soil surfaces, non-uniform changes in soil water and micro-scale advection can result in an uneven distribution of E (Villalobos and Fereres, 1990), making it difficult to assess E and T in detail in such complex environments (Matthias et al., 1986; Yuge et al., 2005, 2014). Under drip-irrigation conditions, soil-surface E and crop-canopy T are physically separated and should receive separate consideration accordingly (Yuge et al., 2005; Wagner-Riddle et al., 1997).

In addition to the phenomenon of wet and dry soil surfaces under drip irrigation, other complex parameters affecting soil water budget measurements include variations in Pw among irrigation treatments; differences in E and sub-surface water flux at the edge of the crop rooting zone as a result of rainfall; and the vertical and horizontal distribution of soil water measurement points within the experimental plot and soil profile. Moreover, when used to calculate ET_c for small plots, soil water budget methods may contain inherent bias due to errors in measurement of rainfall, irrigation water, soil water content and water flux in the rooting zone (Allen et al., 2011a,b; Evet et al., 2012).

Additional calculations may help to improve the accuracy of ETc values for partially wetted environments obtained using soil water content measurements made in the root zone (Vermeirn and Sabling, 1984; Keller and Bliesner, 1990; Allen et al., 1998, 2011a). Keller and Bliesner (1990) offer a simple solution for estimating root zone ETc which belong to wetted and vegetation-covered parts of the field (ETc_{rz}) based on both ETc and plant cover percentage (Pc) using the equations ETc_{rz} = ETc, where Pc = 100%, and ETc_{rz} = 0.1ETc, where Pc < 1%. Savva and Frenken (2002) also suggest various adjustment coefficients (Kr) for estimating ETc_{rz} based on ETc in cases where Pc values vary between 10%–100%.

ETc values of numerous crops irrigated via drip irrigation have been widely reported, along with various indicators representing water use and yields derived using these values; however, very few of these studies provide details about the ETc_{rz} or E from the remaining soil surfaces. This would require either lysimeter studies supported by detailed soil water monitoring, or, alternatively, the development of simple mathematical models that rely on well-known soil water relationships. Therefore, the present study aimed to (1) develop an iterative procedure for calculating soil water budgets using runoff and subsurface water-flux estimations in order to determine ETc_{rz} values, (2) estimate E from the remaining non-drip-irrigation-wetted (i.e. rain-wetted) soil surfaces, (3) calculate red pepper ETc representative of each plot in its entirety for each treatment; and (4) evaluate water-use efficiency (WUE), net economic income (NIC) and financial efficiency (FE) of four different red pepper water-management strategies.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the Black Sea Agricultural Research Institute's Soil and Water Resources Research Station (41° 36′ 8" N, 35° 55′ 8" E) located in the Bafra Plains in the province of Samsun, Turkey. The Bafra Plains, which cover an area of approximately 80,000 ha, have a sub-humid climate (Thornthwaite classification) and long-term annual average precipitation of 694 mm; however, only about 26% (180 mm) of the total precipitation occurs during the red pepper growing season. Maximum and minimum air temperatures occur during August (27.0 °C) and February (3.9 °C), respectively. The average air temperature (T_a) is 14.4 °C, and the annual average relative humidity (RH) is about 72.7% (MGM, 2016). In general, the soils of the Bafra Plains are alluvial and colluvial. The main regional crops include grains (rice, corn and wheat) and vegetables (red pepper, cabbage, pepper, watermelons and tomatoes). Red pepper is grown under irrigation and produces an average annual yield of 35 t ha^{-1}.

Table 1
Physical soil properties of the experimental plots at the Soil and Water Resources Research Station, Bafra Plains.

Soil depth (cm)	Field Capacity[a] (%)	Permanent Wilting Point[a] (%)	Bulk Density (g cm^{-3})	Soil Texture
0–30	30.4	19.2	1.27	C
30–60	30.8	19.7	1.26	C
60–90	30.6	18.8	1.31	C
90–120	27.7	16.3	1.35	CL

[a] Gravimetric based values for field capacity and permanent wilting point.

The physical properties of the experimental plot soils are given in Table 1. In general, these plots have a heavy soil structure and high soil water storage capacity, with the maximum plant-available soil water (PAW) for red pepper (at an effective rooting depth of 60 cm) of approximately 85 mm. Annual chemical analyses of the soil conducted for each experimental year found no problems in terms of salinity. Irrigation water was supplied via an open channel, with electrical conductivity and sodium-absorption rates of irrigation water calculated at 1.4 dS m^{-1} and 3.5, respectively.

2.2. Experimental design

Field experiments were conducted during the 2010 and 2011 growing seasons using a completely randomized block design with three replications. Plot dimensions were 6.0 × 3.5 m, with a distance of 2.0 m between consecutive plots. Four different water-management strategies were evaluated, including 3 irrigation treatments (S1, S2, and S3) and 1 rainfed (S4) treatment. Irrigation scheduling of the full-irrigation S1 treatment was performed according to soil water content, with the amount of irrigation equal to the difference between soil water content and field capacity (FC), when the soil water content reached a management-allowed depletion (MAD) level of 30%-40% of PAW. This is in line with the 25%-40% suggested by Keller and Bliesner (1990) for shallow-rooted, high-value fruit and vegetable crops. Irrigation of the S2 and S3 treatment plots was performed at the same time as irrigation of the S1 plots, but to depths of 70% and 40%, respectively, in relation to the S1 plots. S4 plots were maintained under rainfed conditions, receiving irrigation water only during the establishment period and none thereafter. All plots received the same level of irrigation during the establishment period (20 days after transplanting). A neutron moisture meter (Model 503 DR, Campbell Pacific Nuclear, Martinez, CA) was used to monitor volumetric soil water content every 30 cm down to a soil depth of 120 cm. Access tubes were installed at the center of each plot at a distance of about 10 cm from crop rows, and calibration was performed as described by Koksal et al. (2011) at the start of the experiment. Irrigation scheduling was determined based on soil water measurements conducted in the S1 plots every 2 days during June and September and daily during July and August. In order to improve soil water budget calculations, soil water measurements of all plots were also performed immediately prior to transplantation and each irrigation as well as following the final harvest.

This experiment was conducted using a specially designed drip-irrigation system comprised of a control unit consisting of a water pump, fertilizer tank and three filters, namely a vortex separator, sand-media