ORIGINAL ARTICLE

FIELD WATER SAVINGS ASSOCIATED WITH SATELLITE-BASED ET IRRIGATION CONTROLLERS IN ARID REGIONS

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ABSTRACT

Background: Smart irrigation techniques became lately an essential and vital tool for irrigation water scheduling in water-scarce dry areas to improve irrigation efficiency, producing more agricultural goods with less water input. **Objective:** This study was conducted to investigate the effects of two evapotranspiration based irrigation controllers (ET controllers) on agronomical characteristics and water use of irrigated tomato compared to a time-based irrigation controller under drip irrigation system. **Material and methods:** Experimental site was located at educational station of King Saud University on a sandy loam textured soil. Two brands of ET controllers were selected based on positive water savings results in arid climates. Two types of ET controllers were tested: Weathermatic SL1600; Hunter pro C. Each treatment was replicated three times for a total of nine blocks, which were irrigated through individual irrigation systems. Treatments were compared to each other and to a time-based schedule. **Results:** The results showed that ET controllers adjusted their irrigation schedules to the climatic demand and applied water less than water scheduled by a time clock controller (control treatment). Data revealed that the considerably water saving over the entire study period was obtained by Hunter (28%). Weathermatic reflected a similar trend to water savings with similar statistical results (27%) when compared to control, but it was poorer than Hunter treatment. Water productivity was significantly increased by 64% and 50%, respectively under Hunter and Weathermatic systems as compared to control. Moreover, the highest physiological parameters, was obtained from Hunter pro C followed by Weathermatic SL 1600 treatment as compared to control. **Conclusion:** Irrigation scheduling using surface drip and sensor-based irrigation systems demonstrated that ET controllers could achieve higher levels of water savings and water efficiency while maintaining competing yield.
Keywords: *Smart controllers, water productivity, water savings, drip irrigation.*

1. INTRODUCTION

Smart irrigation controllers are defined as controllers that save outdoor water use by monitoring and using information about site conditions (such as soil moisture, rain, wind, slope, soil, plant type, and more), and then applying the right amount of water upon on those factor. These irrigation controllers receive feedback from the irrigated system and then schedule or adjust irrigation duration and/or frequency accordingly. Smart irrigation controllers include (i) evapotranspiration (ET) based irrigation controllers (ET controllers), (ii) Soil water sensor based irrigation controllers [7]. In soil water sensor based irrigation controllers, data from soil moisture sensor is used to allow or bypass timed irrigation events [2]. ET controllers are divided into three subgroups according to the way the controllers receive weather data. These groups are i) Standalone Controllers, ii) Signal-Based Controllers, and iii) Historical-based controllers [7].

Standalone controllers use sensors installed on-site to measure weather site conditions and then calculate real-time evapotranspiration (ETo) based on the data collected [12]. The sensors collect readings at intervals anywhere from every second to every fifteen minutes and then a daily ETo is calculated from those values. In signal-based controllers, a wired (phone) or wireless (cellular or paging) communication is utilized to receive ETo data [7]. Weather information is gathered from publicly available or dedicated weather stations in the controller location range. Some manufacturers gather the climatic information data from the weather stations, calculate a daily ETo value, and then broadcast the value directly to the controller each day [8]. Historical-based controllers depend on historical ETo information for the area. Typically, monthly historical ETo is programmed into the controller by the manufacturer or installing contractor and then adjusted based on site specific weather measurements to better account for differences in current ETo from historical trends [4].

Devitt et al. (2008) found that water applied by signal-based ET controllers in Las Vegas homeowner landscapes was reduced by 20% on average as compared to sites without an ET-based controller [6]. Davis et al. (2009) reported that ET controllers saved water by 42% as compared to time-based irrigation controllers and turfgrass quality not affect adversely [5]. A study conducted in Florida by Davis et al. (2007) from 1 July 2006 to 30 November 2006 found that two of three brands of ET controllers tested compared to a 2 days/week irrigation schedule with no irrigation control devices were capable of reducing water applied by 20–60%, while maintaining acceptable turf quality [3]. McCready et al. (2009) examined irrigation water applied using two brands of ET controllers compared to the irrigation applied, based on the recommended irrigation rates and found that water savings were between 25% and 62% [13]. The testing was performed under dry to normal Florida rain conditions. The objective of this research was to investigate the use of ET controllers for agricultural applications under drip irrigation system.

2. MATERIALS AND METHODS

2.1. Study area

A 1,000 m^2 area located at educational station of King Saud University, Riyadh- Saudi Arabia (24° 43′ N latitude, 46° 43′ E longitude, 635 m altitude) was prepared, leveled and then divided into three main fields separated with buffer zones of 5 m (Fig. 1). Each field was subdivided into three plots with surface-area dimensions of 7 m wide x 10 m long. The soil consists of 69% sand, 15% silt, 16% clay in upper 60 cm soil profile, and could be classified as sandy loam. The bulk density varies from 1.61 to 1.63 g cm^{-3}. The average soil water content at field capacity from surface soil layer down to 60 cm depth at 20 cm intervals was 16 %, and the permanent wilting point for the corresponding depths was 6 % respectively. Some other physical and chemical properties of the experimental soil are displayed in Tables 1 and 2.

Table 1: The table presents some physical soil properties of the experimental site.

Soil depth (cm)	Particle size distribution (%)			BD g cm^{-3}	PWP m^3m^{-3}	FC m^3m^{-3}
	Sand%	Silt%	Clay%			
0-20	70.82	16.10	13.08	1.63	5.32	14.74
20-40	66.80	14.09	19.11	1.62	6.54	17.27
40-60	68.81	16.10	15.09	1.61	6.54	15.90

BD=Bulk Density, PWP = Permanent Welting Point and FC = Field Capacity

Table 2: The table presents some chemical soil properties of the experimental site.

Soil depth (cm)			Cations meq l^{-1}				Anions meq l^{-1}		
	pH	EC (ds m^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	$CaCO_3$%
0-20	7.2	2.0	15.3	4.5	6.5	0.5	10.0	8.6	26
20-40	7.5	1.3	6.5	2.6	3.7	0.4	5.3	4.0	24
40-60	7.3	2.7	11.3	9.0	6.9	0.9	11.5	8.9	13

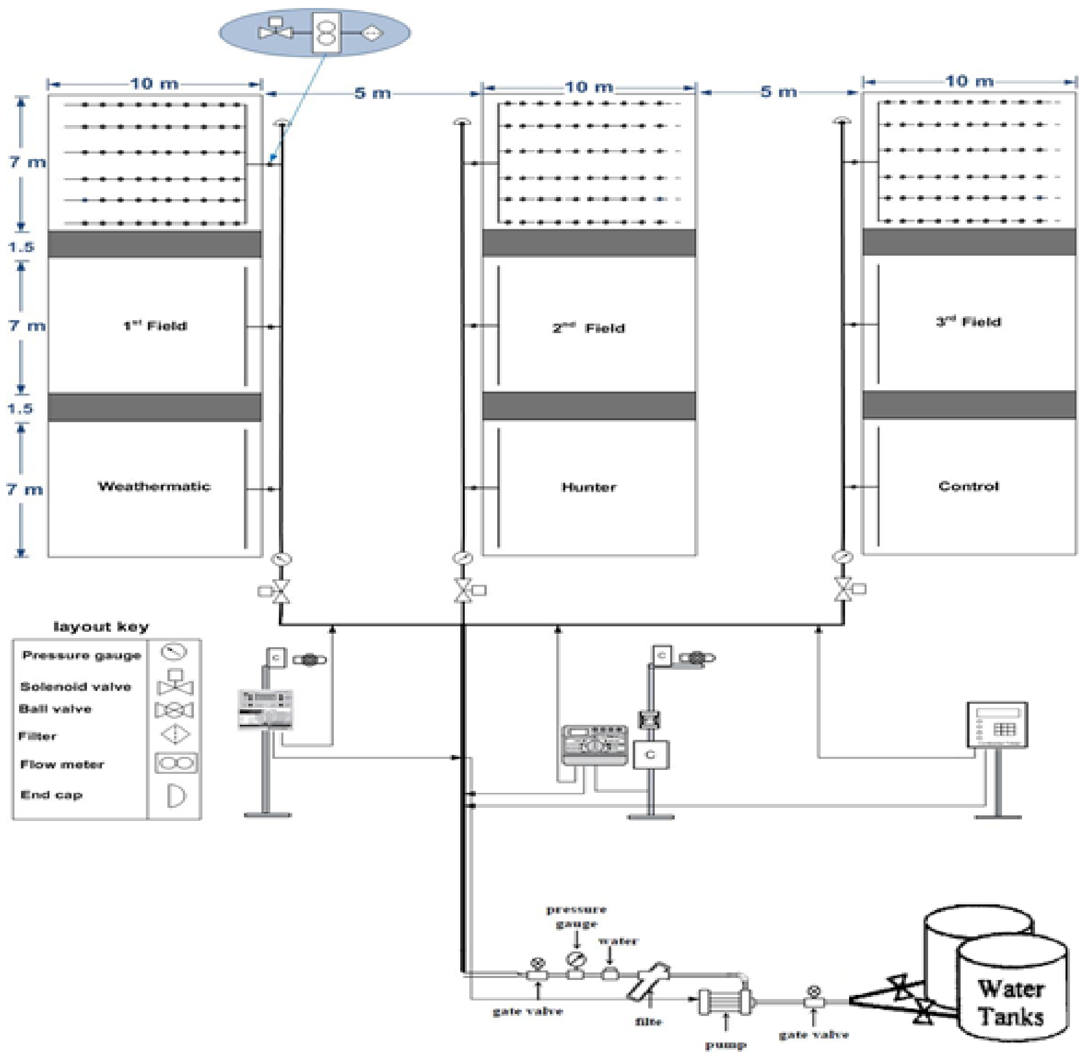

Figure 1: The figure presents the schematic design of the experimental field (not to scale)

2.2. Climatic conditions: The experimental field is situated in arid climatic region. The averages of air temperature, relative humidity, wind speed, sunshine duration and total precipitation were monitored by an in-situ meteorological station (Davis vantage pro2). The air water vapor pressure deficit was calculated using daily and hourly average temperatures and relative humidity. Finally, the reference evapotranspiration (ETo, mm day^{-1}) was calculated according to the Penman-Montieth equation [1]:

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma[(900U_2)/(T+273)](e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where Rn and G are daily net radiation and soil heat flux in MJ m^{-2}, respectively, Δ is the slope of saturation vapor pressure curve (kPa °C^{-1}), U_2 is the average daily wind speed at 2 m above soil surface (m s^{-1}), γ is the moisture constant (kPa °C^{-1}), T is the average daily air temperature at 2 meter height (°C) and (es - ea) is the saturated vapor pressure deficit (kPa).

2.3. Calculated irrigation requirement: Irrigation-scheduling program in first and second fields has been executed automatically based on local climate conditions collected and processed by the intelligent system of ET controllers (Fig. 2). The plots in third field (control) were irrigated and controlled manually by standard time-based controller through ETo values acquired from a nearby-automated weather station. Water demand of tomato plants was then determined by multiplying calculated ETo by a crop coefficient, Kc. Once water demand has been determined, the operational required time has been applied to start various time-based irrigation schedules on tomato crop (equation 2).

$$Ti = \frac{ETo \times K_c \times A_p \times K_r}{E_i \times (1 - LR) \times Qs} \quad (2)$$

Where Ti is irrigation time (min), ETo is reference evapotranspiration (mm day^{-1}), Kc is crop coefficient, Ap is plot area (m^2), K_r is a wetted area percentage (%), E_i is irrigation system efficiency, LR is leaching requirements (%) and Qs is irrigation system discharge (lit min^{-1}).

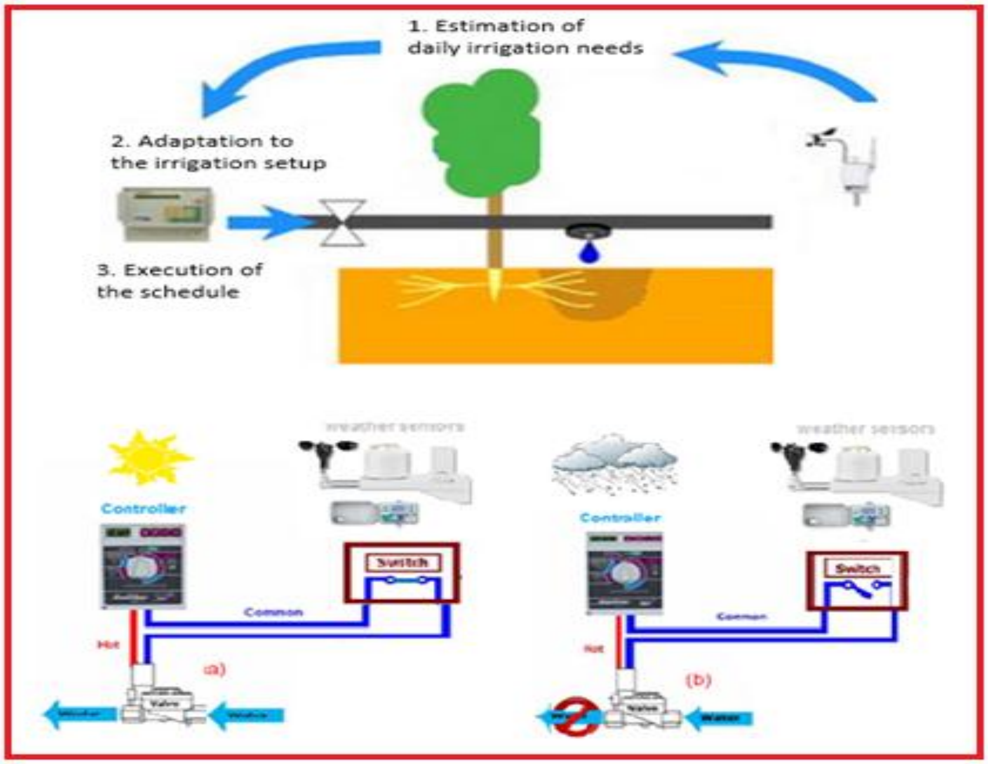

Figure 2: The figure shows a general algorithm for automated scheduling of drip irrigation.

2.4. Leaching requirements: Leaching requirements (LR) were calculated by the equation described below:

$$LR = \frac{EC_W}{2max.EC_e} . \frac{1}{LE} \quad (3)$$

Where EC_w is the electrical conductivity of water (mmho cm^{-1}), ECe is the electrical conductivity of soil extract (mmho cm^{-1}), max ECe is the maximum electrical conductivity of soil extract tolerated by tomato plants (mmho cm^{-1}) and LE is the leaching efficiency.

2.5. Water productivity: Water productivity (WP) concepts were calculated as suggested by Howell (2001) [10].

$$WP = \sum_{i=1}^{n} \frac{Y}{WA} \quad (4)$$

Where n is number of replicates per treatment, i is iteration, Y is the yield achieved (kg) and WA is water applied (m^3).

2.6. Plant measurements: Nema tomato variety was used in this study. Fertilizers were divided and delivered with irrigation in all treatments during the growing growth. Two months after transplanting, random samples of three plants from each sub-plot were taken to measure vegetative growth (stem fresh weight, plant fresh weight, stem dry weight and plant dry weight).

2.7. Statistical analysis: The data were analyzed using SPSS Verion-21 statistical software to obtain descriptive statistics for sampled data. However, ANOVA was used for comparison among different plots. All the treatment means were compared for any significant differences using the Duncan's multiple range tests at significant level of P 0.05.

3. RESULTS AND DISCUSSION

3.1. Weather conditions

The observed daily average values of the climatic variables in the experimental site are shown in Figure 3. The data revealed that the maximum mean monthly temperature was 34.54 °C during May, while the lowest mean monthly temperature was 13.38 °C during February. The highest mean relative humidity was 34.15% during February, whilst the lowest mean relative humidity was 24.17% during May month. The region also presents an irregular rainfall regime with a rainy season period, in which the maximum monthly rainfalls were 8.87 and 5.8 mm in May and April, respectively. The wind speed increased from February to April and then decreased toward the end of the observational period, with an average value of 5.73 km hr^{-1}. The maximum mean daily value of net radiation was 23 MJ $m^{-2}day^{-1}$ in May.

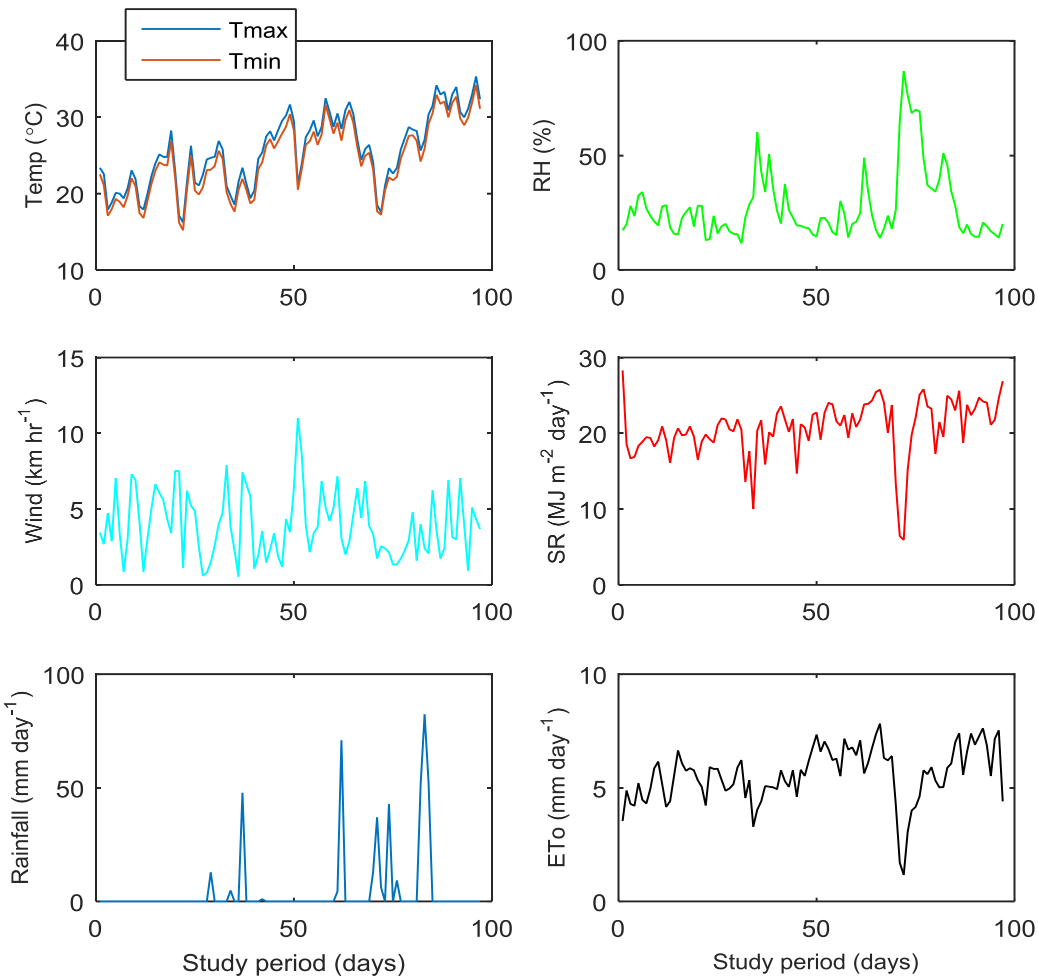

Figure 3: The figure shows the average daily values of climatic conditions at the experimental site.

3.2. Evapotranspiration (ET) controllers

Evapotranspiration (ET) controllers have been used to schedule irrigation in tomato under surface drip irrigation system by using Weathermatic SL 1600 and Hunter-Pro C controllers. Irrigation depth added to tomato replications (R1, R2 and R3) by Weathermatic, Hunter and control treatments was separately plotted on weekly basis (Figs. 4, 5 and 6). Water depth applied for the different irrigation treatments varied, and significant differences among treatments were observed. Minimum and maximum weekly values of irrigation depths added to the three fields in initial growth and vegetative phases were 7.31 and 46.18, 9.50 and 51.9, 53.7 and 15.67 mm under Hunter, Weathermatic and control, respectively. The reason is irrigation water needs are generally low during the initial growth stages, but increases exponentially during the vegetative phases. In flowering and fruiting stages, there was a downward trend when weekly values of the water applied by Hunter, Weathermatic and standard controllers fell to 30, 26 and 44, respectively. It is also possible to observe that quantity of water applied had no statistical significance amongst replications under each treatment; mainly because of the dynamic irrigation scheduling for each group of replications was executed by the same controller.

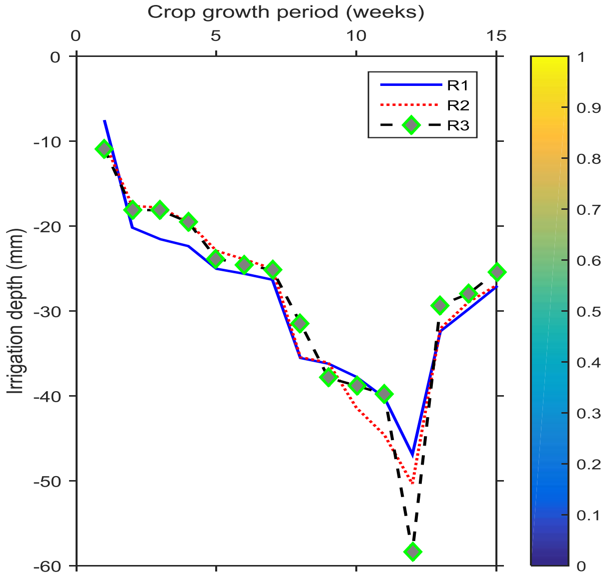

Figure 4: The figure presents the irrigation depth applied through the weathermatic controller.

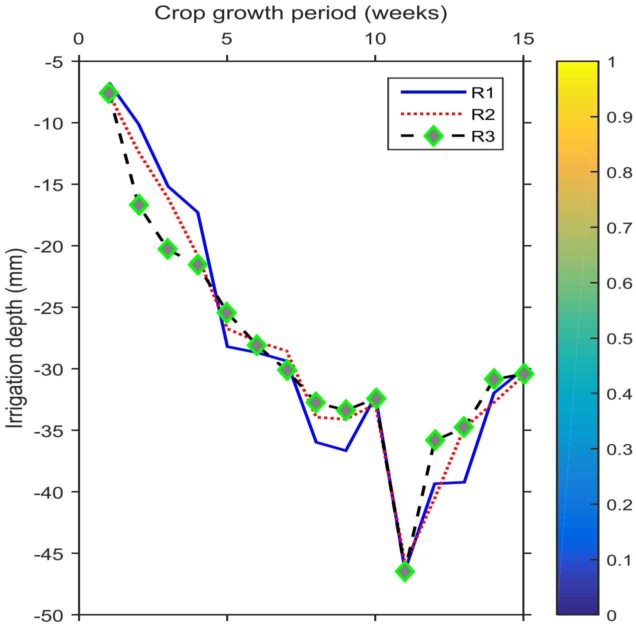

Figure 5: The figure presents the irrigation depth applied through the hunter controller.

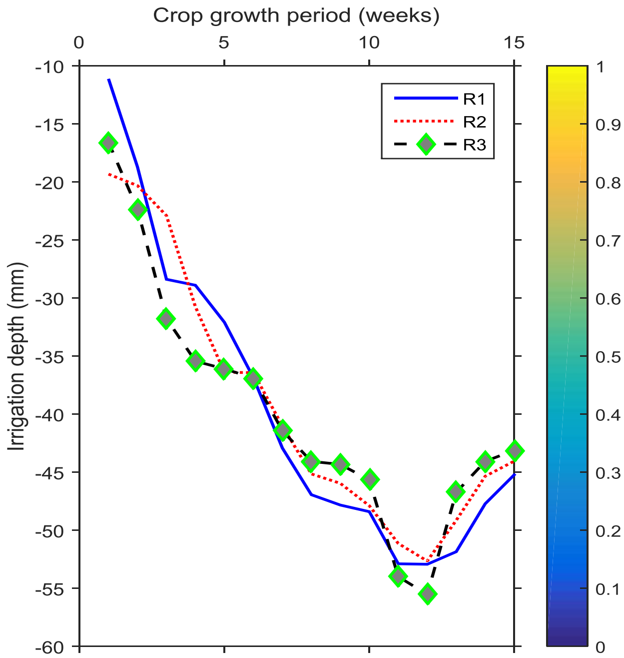

Figure 6: The figure presents the irrigation depth applied through the traditional controller.

3.3. Amount of applied irrigation water

Figure 7 compares irrigation depth added to three fields through three different irrigation controllers, namely Weathermatic, Hunter and standard (control). There was a gradual increase in irrigation depth over initial, vegetative and mid stages in which irrigation depth varied between 9 and 51, 7 and 46, 15 and 54 mm under Weathermatic, Hunter and standard controllers, respectively. By contrast, Irrigation depth decreased in flowering and fruiting stages when average weekly values of water applied by Weathermatic, Hunter and standard controllers fell to 28, 34 and 46 mm, respectively. Figure 7 also revealed that the considerably water saving over the entire study period was obtained by Hunter (28%).

Weathermatic reflected a similar trend to water savings with similar statistical results (27%) when it compared with control, but it was poorer than Hunter treatment. Mainly because of the differences in runtimes, irrigation frequencies and the number of irrigation events bypassed under Weathermatic, Hunter treatments [15, 9]. Additionally, ET controllers showed a great potential to save water ranged from 38% by Weathermatic to 39 % by Hunter as compared to irrigation methods practiced by the local framers (700 mm in average) in the area. This could be attributed to more accurately water applied by ET controllers, especially over cold months.

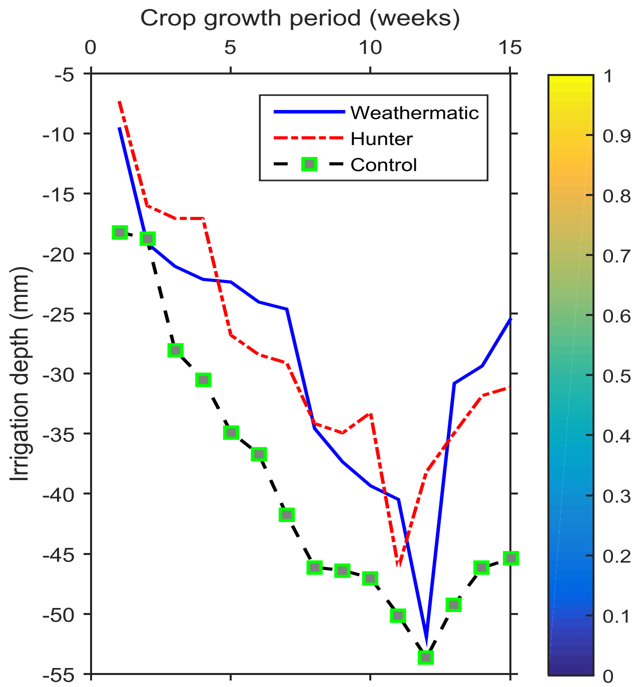

Figure 7: The figure presents the irrigation depth scheduled by ET controllers' vs control.

3.4. Water productivity

Water productivity data affected ET controllers and a time-based controller (control) under drip irrigation system are shown in Figure 8. It is obvious that the highest water productivity was obtained in plots irrigated by Hunter (18.52 kg m^{-3}), while the lowest water productivity was obtained in plots irrigated with control system (6.69 kg m^{-3}). In details, water productivity was significantly increased by 64% and 50%, respectively under Hunter and Weathermatic systems as compared to control. These results were consistent with Sensoy et al. (2007) and Kirnak et al. (2005) [11, 14].

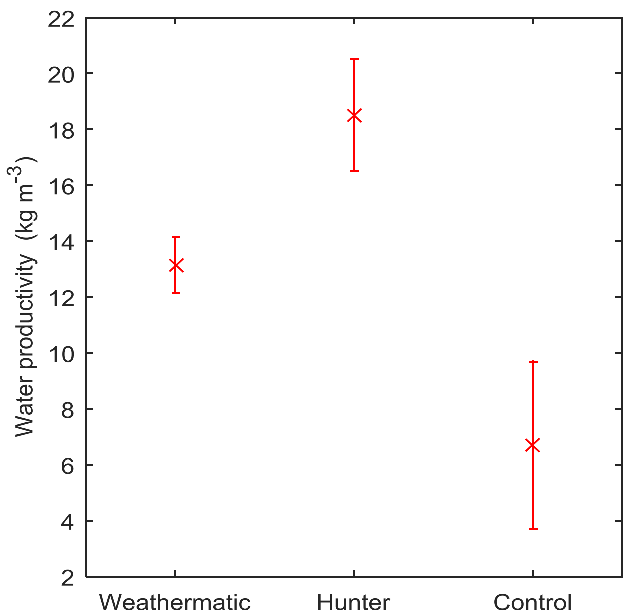

Figure 8: The figure presents the effect of irrigation systems on water productivity.

3.5. Agronomic characteristics

Cultivated tomato crop showed a significant differences in agronomic traits (vegetative growth, fruit quality and fruit yield traits) in response to water applied by ET controllers and control treatment (Tables 3, 4 and 5). Overall, it can be depicted that average values of agronomical traits were in order of Hunter > Weathermatic > control. In details, results of analysis indicated that values of Plant fresh weight (g), Plant dry weight (g), Stem fresh weight (g) and Stem dry weight (g) increased by 67% and 28.3%, 30.6% and 30%, 50.2% and 22.1%, 28.7% and 25.2% under Hunter and Weathermatic treatments, respectively compared to control (Table 3). The increase in values of Dry matter (%), Total soluble solid (%), Vitamin C (g 100 g^{-1} FW) and total acidity (%) were 51.4% and 41.8%, 52.2% and 50.3%, 52.2% and 50.3% under Hunter and Weathermatic treatments, respectively compared to control treatment (Table 4).

The values of Early yield (kg m^{-2}), total yield (kg m^{-2}), average fruit weight (g) and number of fruit per plant were also significantly increased by 50.5% and 31.3%, 50.4% and 31.3%, 41.9% and 21.2%, 53.8% and 48% under Hunter and Weathermatic treatments, respectively compared to control treatment (Table 5). This could be due to the appropriate use of surface drip and sensor-based irrigation systems that closely match the day-to-day water use of plants.

Table 3: The table presents the tomato vegetative traits effected by different irrigation schedules.

Treatments	Plant height (cm)	Number of branches	Plant fresh weight (g)	Plant dry weight (g)	Stem fresh weight (g)	Stem dry weight (g)
Weathermatic	66.40c	7.00b	492.47d	117.40b	174.67c	37.20c
Hunter	71.10b	9.00 c	1069.57a	118.20b	273.36a	39.00b
Control	53.58d	5.00c	352.80f	82.00d	136.00e	27.80d

Means with the same class followed by the same letter are not significantly different according to LSD (0.05)

Table 4: The table presents the tomato quality traits affected by different irrigation schedules.

Treatments	Fruit length (cm)	Fruit diameter (cm)	Dry matter (%)	Total soluble solid (%)	Vitamin C (g/100 g FW)	Total acidity (%)
Weathermatic	5.07c	4.97d	5.37c	6.33c	26.93a	0.58d
Hunter	5.33b	5.40b	6.43a	6.57a	27.17a	0.61a
Control	3.96d	3.96e	3.12f	3.14f	14.58d	0.32f

Means with the same class followed by the same letter are not significantly different according to LSD (0.05)

Table 5: The table presents the tomato yield components affected by different irrigation schedules.

Treatments	Early yield (kg/m^2)	Total yield (kg/m^2)	fruit weight (g)	Fruit/ plant
Weathermatic	3.40e	5.69e	98.60d	21.00d
Hunter	4.70b	7.90b	133.73b	24.00c
Control	2.34f	3.91f	77.63f	11.00e

Means with the same class followed by the same letter are not significantly different according to LSD (0.05)

4. CONCLUSION

This interdisciplinary study provides a complete evaluation of tomato irrigation research by including key physiological and production measurements by irrigation treatments. Tomato irrigation may be managed successfully either by Hunter pro C or Weathermatic SL1600 controllers without influencing the measured physiological and production characteristics. ET controllers demonstrated that they could save irrigation water by 28% and increase water productivity greatly up to 64%, while maintaining competing yield as compared to a time-based irrigation schedules (control).

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