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RESEARCH ARTICLE

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Evaluating two irrigation controllers under subsurface drip irrigated tomato crop

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Abstract

Smart systems could be used to improve irrigation scheduling and save water under Saudi Arabia's present water crisis scenario. This study investigated two types of evapotranspiration-based smart irrigation controllers, SmartLine and Hunter Pro-C2, as promising tools for scheduling irrigation and quantifying plants' water requirements to achieve water savings. The effectiveness of these technologies in reducing the amount of irrigation water was compared with the conventional irrigation scheduling method as a control treatment. The two smart irrigation sensors were used for subsurface irrigation of a tomato crop (cv. Nema) in an arid region. The results showed that the smart controllers significantly reduced the amount of applied water and increased the crop yield. In general, the Hunter Pro-C2 system saved the highest amount of water and produced the highest crop yield, resulting in the highest water irrigation efficiency compared with the SmartLine controller and the traditional irrigation schedule. It can be concluded that the application of advanced scheduling irrigation techniques such as the Hunter controller under arid conditions can realise economic benefits by saving large amounts of irrigation water.

Additional key words: smart irrigation; ET controllers; subsurface irrigation; automatic controllers; irrigation water use efficiency; arid region; tomato yields.

Abbreviations used: C (control irrigation); Dg (depth of irrigation water); (Dg)t (total depth of irrigation water); DW (dry weight); ET (evapotranspiration); ETr (reference evapotranspiration); FW (fresh weight); H (Hunter controller); ICS (irrigation control system); IWUE (irrigation water used efficiency); Kc (crop coefficient); SDI (subsurface drip irrigation); SL (SmartLine controller); WUE (water use efficiency); Y (total fresh yield).

Authors' contributions: Conceived and designed the experiments, performed the experiments, analyzed the data, wrote the paper, and revised of the manuscript: HMAG, FSM and MSAEM. Obtained funding, administrative and technical coordinated the research project: HMAG.

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Introduction

The sustainability of agricultural production depends on the conservation, appropriate use and management of scarce water resources, especially in arid and semi-arid areas where users compete over limited water resources (Provenzano *et al.*, 2013) and irrigation is required for the production of food and cash crops (Douh & Boujelben, 2011). Various irrigation systems have been introduced to save agricultural water use and particularly to increase water use efficiency (WUE). Subsurface drip irrigation (SDI) is considered the most efficient irrigation method. The installation of drip irrigation pipes below the soil surface potentially reduces water loss due to soil evaporation, thus increasing WUE (Ayars *et al.*, 1999). Moreover, SDI reduces health hazards and groundwater contamination due to the use of wastewaters (Mguidiche *et al.*, 2015). SDI systems allow minimal water loss while maintaining high levels of crop production (Mailhol *et al.*, 2011; Rallo *et al.*, 2012; Cammalleri *et al.*, 2013; Baiamonte *et al.*, 2015). However, to obtain high WUE values, it is necessary to schedule irrigation using sensor-based methods to detect the soil and crop water status. Elmaloglou *et al*. (2010) found that although SDI systems can increase WUE, they can only do so if they are designed to meet the soil and plant conditions. Al-Omran *et al*. (2010) concluded that SDI increased the yield and WUE of tomato crops and reduced the amount of irrigation water by improving the root-zone moisture distribution.

Technologies designed for automatic irrigation scheduling to maximize WUE are usually based on monitoring the soil and crop water status (Muñoz-Carpena & Dukes, 2005). The following three methods, for example, are designed to match irrigation with crop water requirements: weather-based methods that use reference evapotranspiration (ETr) (Allen *et al*. 1998); soil water-based methods that use soil moisture sensors (Evett, 2007); and soil–water-balance calculations and plant stress-sensing techniques (Jones, 2004). Many researchers have investigated the automation of irrigation systems through direct and indirect measurements of soil water content, using devices such as WaterMark and EnviroSCan tensiometers. Using inexpensive tensiometers for irrigation scheduling is quite easy and provides accurate readings (Schlegel *et al*., 2012). Among the commercial tensiometers, WaterMark is widely used because of its favorable technical features for on-farm use, low cost, ease of installation and durability (Thompson *et al*., 2006). The EnviroSCAN is another type of sensor used for the automated irrigation of many crops in different soil types, and which allows easy access to stored data (Fares & Alva, 2000). These sensors have been used for many years and subjected to continual refinements in terms of calibration efforts in the field and laboratory (El Marazky *et al*., 2011; Provenzano *et al*., 2015). Soil moisture sensors are used to improve irrigation scheduling and to save both water and energy (Papanikolaou & Sakellariou-Makrantonaki, 2013).

ET controllers are also used to automate irrigation and crop needs. This technology, sometimes referred to as “intelligent technology” (McCready *et al*., 2009), provides irrigation based on actual water requirements and crop use and also takes weather factors into account. Davis *et al*. (2010) demonstrated that ET controllers applied only half of the theoretical irrigation requirement for each irrigation event and, on average, irrigation adequacy decreased when the ET controllers were allowed to irrigate any day of the week. Al-Ghobari & Mohammad (2011) reported that intelligent irrigation saved up to 25% of water compared with the control method, while maintaining a competitive yield. Mohammad *et al*. (2013) revealed that the intelligent irrigation system offered a significant advantage in managing the irrigation of tomato crops and had significant effects on the WUE and irrigation water used efficiency (IWUE). The system reduced irrigation water use by up to 26% compared with the control system.

The objective of the current study was to investigate the potential water-saving and crop-yield effects of two smart irrigation controllers, *i.e.* SmartLine and Hunter, applied under field conditions for automatic irrigation scheduling of tomato crops in an arid region. The study also evaluated the suitability of the soil moisture sensors for providing instantaneous information on soil water status.

Material and methods

Site description

This study was carried out at the Experimental Farm of the College of Food and Agriculture Sciences of King Saud University, Riyadh (24°43´N latitude, 46°43´ E longitude and 635 m altitude) during the spring of 2013. The experimental study area was 1200 m^2 (40 m × 30 m). The soil was sandy loam (85.9% sand, 6% silt and 8.1% clay). The experimental area was divided into three plots 7.0 m large and 10 m long, separated by buffer zones of 1.5 m (Fig. 1). Two fields were managed by modern electrical controllers (Weathermatic and Hunter Companies) via smart irrigation systems, one using SmartLine (SL-1600) and the other using Hunter Pro-C2. These controllers are inexpensive and available on the local market. The third field was managed as the control treatment, which was based on the ET$_r$ estimated using microclimatic data obtained from an automatic weather station, as shown in Fig 1. The monitored parameters were maximum and minimum temperature, maximum relative humidity, solar radiation and wind speed. The distance from the weather station to the experimental plot was 5 m. The climate in this region is classified as arid, and the climatological data measured at the experimental site during this study period are shown in Table 1.

Irrigation system layout

For the SDI fields, the laterals were installed at a depth of 15 cm below the soil surface. The SDI systems had a 16 mm inside diameter and wall thickness of 1.1 mm, and were installed at intervals of 1 m with 20 in-line emitters spaced 50 cm apart, characterized by a nominal discharge of 3.5 L/h at 80 kPa. The drip lines in each plot were connected to a common sub-main irrigation line at the inlet side of the plot and a common

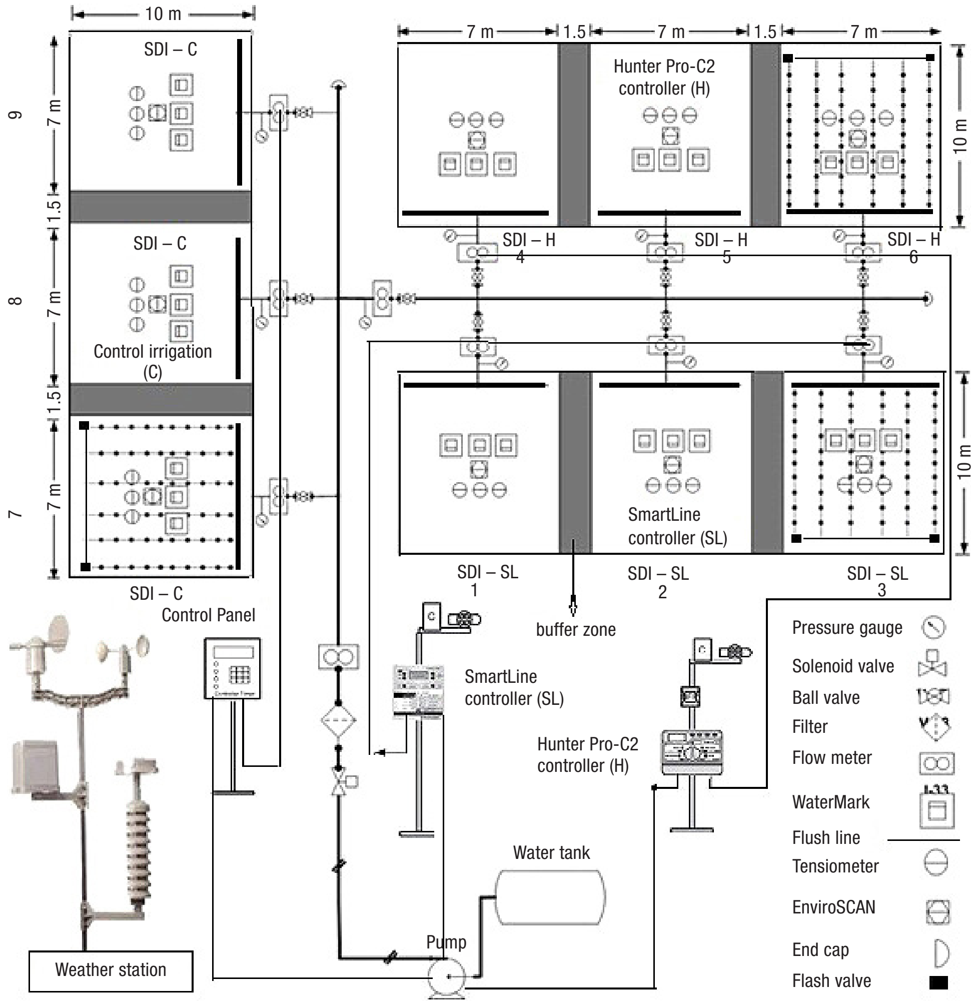

Figure 1. Field experimental layout. C, control irrigation; SDI, subsurface drip irrigation.

Table 1. Monthly meteorological variables for the experimental site. 2013 Season.

Month	Tmax °C	Tmin °C	MRH %	Total rainfall mm	SR MJ/m²/d	WS m/s	ETr mm/day
February	26.28	13.40	26.96	0.00	20.56	1.60	4.62
March	30.03	16.39	19.02	0.01	25.76	1.54	5.97
April	32.86	21.41	28.53	0.27	23.01	1.93	6.20
May	37.64	25.25	25.06	0.18	24.11	1.65	6.90

Tmax = Maximum temperature, Tmin = minimum temperature, MRH = maximum relative humidity, SR = solar radiation, WS = wind speed, and ETr = reference evapotranspiration.

flush line and flush valve at the distal end of the plot. The experimental preparation steps involved the installation of the rest of the irrigation networks such as valves, flow meters and pressure meters.

SmartLine and Hunter controllers work according to the presetting's of each controller, based on the location of the site, treatment inputs and weather readings from the weather station. The controllers also require data on the irrigation system, plant and soil types to be able to calculate the run times for each treatment. Thus, the decision to start a specific station is based on a minimum irrigation amount, to prevent shallow watering.

The criteria used to irrigate the control treatments were based on the crop ET (ETc) based on the measured climatic variables. Hence, the net irrigation requirements were computed using the ETr and effective precipitation. The ETc values for the control plot resulted from the product of ETr by the crop coefficient (Kc) obtained from Allen *et al.* (1998). Based on the area of the field and the emitter flow rate, the required amount of water per irrigation event was then determined.

Irrigation management and agronomic practices

The three fields were cultivated with tomato crops (cv. Nema). Each field was divided into three 70 m^2 plots (7 m × 10 m), in which seven laterals were installed. The tomato plants were transplanted on February 7, 2013 along a single row for each bed.

The controllers were programmed in situ, taking into account the type of crop and the prevailing environmental conditions. The net irrigation requirements were computed using the effective precipitation estimates. Daily and weekly ETc rates for tomatoes during the growth period were determined for the irrigation control system treatments. The irrigation water depths (Dg) and cumulative depths added to the crop under each treatment, with three replications, were monitored by flow meters and were recorded throughout the growing season.

All of the treatments followed the same application of fertilizers and pesticides for insect and disease control. Phosphate (200 kg/ha) and potassium (100 kg/ha) were added before planting the seedlings. The rates after planting were 300 kg N/ha and 100 kg/ha potassium sulfate during the growth period, added in five equally spaced installments.

Harvest-ripe fruits were manually picked and weighed twice a week, starting on 25 April and continuing until the end of the experiment, on 25 May. The last irrigation event was on 20 May. The fruit yield and its components were evaluated from eight plants collected from the central rows of each plot during the harvest period. At each fruit harvesting the plant height (cm), branch number, fruit length (cm), fruit diameter (cm), fruit shape index (length/diameter), average fruit weight (g) and total yield (ton/ha) were also measured in each plot.

Monitoring soil water status

Three devices to measure soil water tension, WaterMark, Tensiometer and EnviroSCAN, were installed in the middle of each plot at three depths: 20, 40 and 60 cm. The EnviroSCAN data were transmitted remotely to the computer unit via the internet in the forms of reports and graphs.

All of the sensors were read daily at 8:00 a.m. from Saturday to Wednesday; at the same time, once every two weeks, 500 g of disturbed soil samples from each location were collected to determine the gravimetric soil water content. The EnviroSCAN sensors, communicating with a radio telemetry system, were monitored continuously and averaged at 30-min time intervals. Measurements were registered from February to June. The purpose of our sensor network was to monitor the soil moisture variations in each plot over time.

Water use efficiency

IWUE was expressed as the ratio between the yield and the total amount of applied water (Lovelli *et al.*, 2007), according to the following equation:

$$\mathrm{IWUE} = \left(\frac{Y}{(Dg)_t} \right)$$

in which Y is the total fresh yield (kg/m^3), and (Dg)t is the amount of seasonally applied irrigation water (mm).

The experiments used a split-plot design; analysis of variance (ANOVA) was performed in SAS version 8.1 (SAS, 2008) to evaluate the statistical differences between treatments in terms of vegetative growth, fruit yield components, fruit quality traits, yield and IWUE. The means were separated using a revised least significant difference (LSD) test and a significance level of $p < 0.05$ was assumed to compare the treatment means (Steel & Torrie, 1980).

Results and discussion

The soil water status measured by the Tensiometer, WaterMark and EnviroSCAN devices in the SDI plots under the SmartLine, Hunter and control treatments were plotted throughout the growing season as a function of the number of days after planting (Figs. 2-4). Figure 2 represents the average soil matric potential detected in the three layers under the SmartLine controller. The soil matric potential differed slightly between the three layers, with values ranging from 10 to 20 kPa during the initial five weeks. After this period, the differences between the three depths increased: the soil water potential from 60 days after planting was 22 kPa at a depth of 60 cm, compared with only 35 kPa at a depth of 20 cm on the same day. At the end of the season the soil water potentials had changed: the tension at 20 cm depths was the lowest at 35 kPa, compared with 55 kPa in the third layers.

The soil water potential data measured by WaterMark at the three depths in all of the treatments were different from those measured by the Tensiometers. Figure 2 shows that the soil water potential measured by WaterMark in the SmartLine treatment increased with the growing period. The soil water potential values from day 35 to day 70 increased and then dropped sharply. This variation in the soil water potential could be due

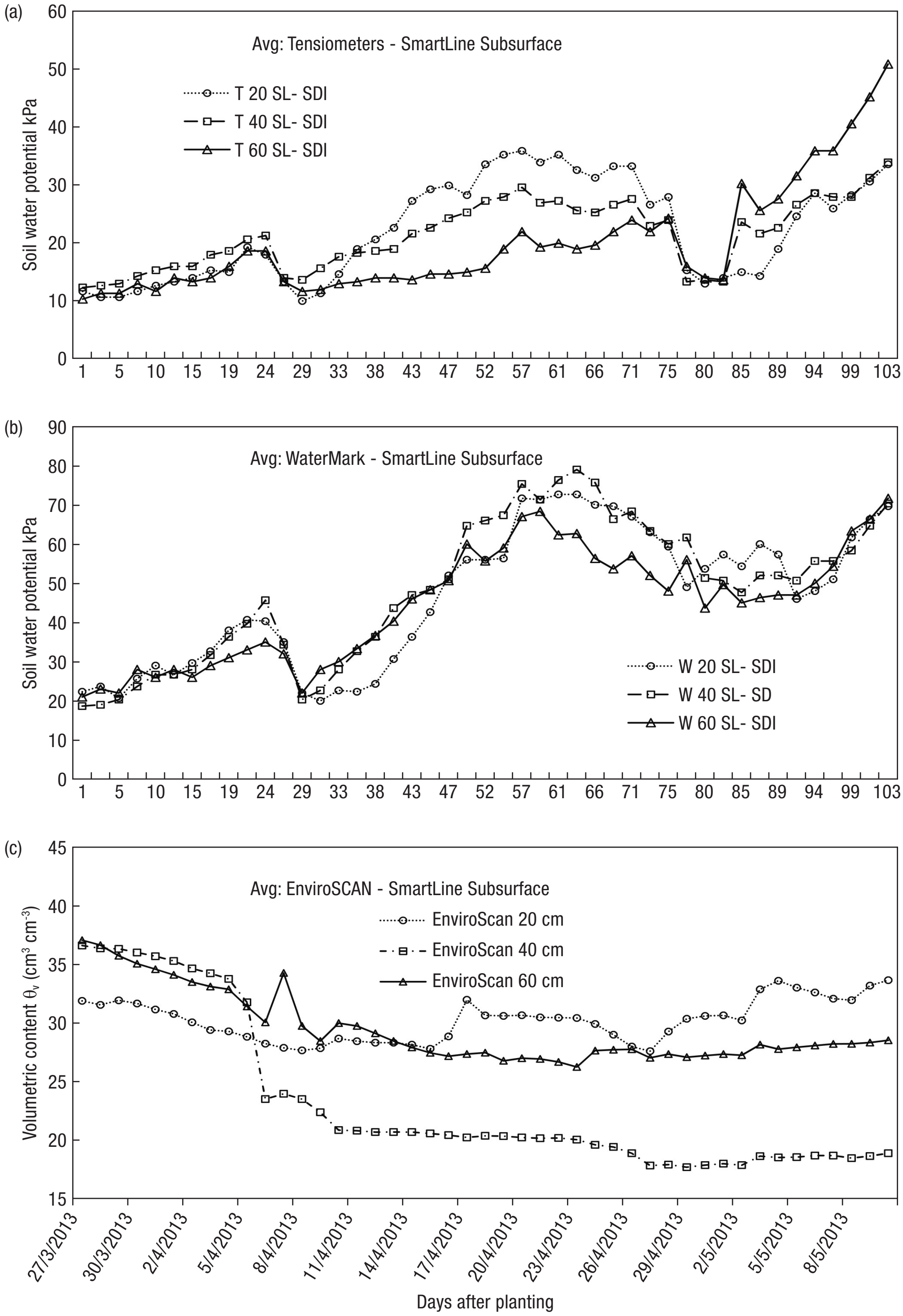

Figure 2. Soil water status measured by tensiometers (a), WaterMark (b), and EnviroSCAN (c) for the Smart Line subsurface. SDI, subsurface drip irrigation. SL, SmartLine controller.

to a lack of irrigation water during this period. The average soil matric potentials at the three depths in the SmartLine treatment were clearly different, ranging from 20 kPa at day 1 to a maximum of 80 kPa at day 58. In contrast, Figure 2 shows that the trend of the soil volumetric content measured by EnviroSCAN for the same treatment decreased in the early growing stage.

Figure 3 shows the soil water status measured within the three plots under the Hunter controller treatment. The observed variables followed similar trends to those of the SmartLine treatment throughout the season for the three depths. The figure shows that the volumetric soil water content measured by EnviroSCAN for the Hunter treatment gradually decreased over the growth

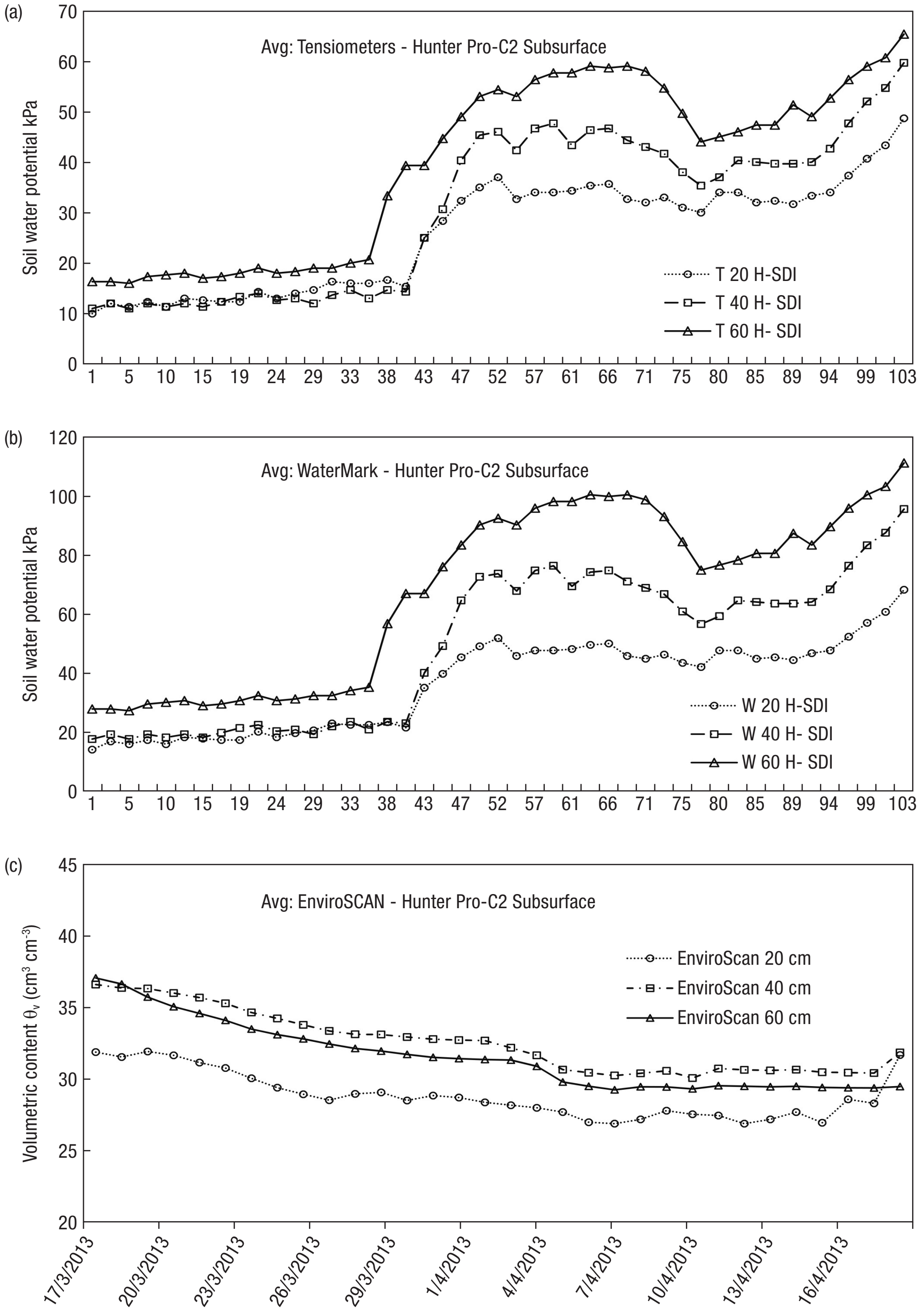

Figure 3. Soil water status measured by tensiometers (a), WaterMark (b), and EnviroSCAN (c) for the Hunter subsurface.

period until the end of the season. The decrease in soil moisture content throughout the season indicates that the average application rate of each irrigation event did not meet the crop's water needs adequately.

The results presented in Figure 4 show the soil water status detected by the three sensors for the control treatment. The figure shows the variations in the soil matric potential and water content during the growth season. The soil matric potential for the three types of sensors differed for the three depths. Similarly, the volumetric soil water content measured by EnviroSCAN for the three treatments varied accordingly.

The EnviroSCAN system measures changes in frequency related to the bulk permittivity of the soil. The

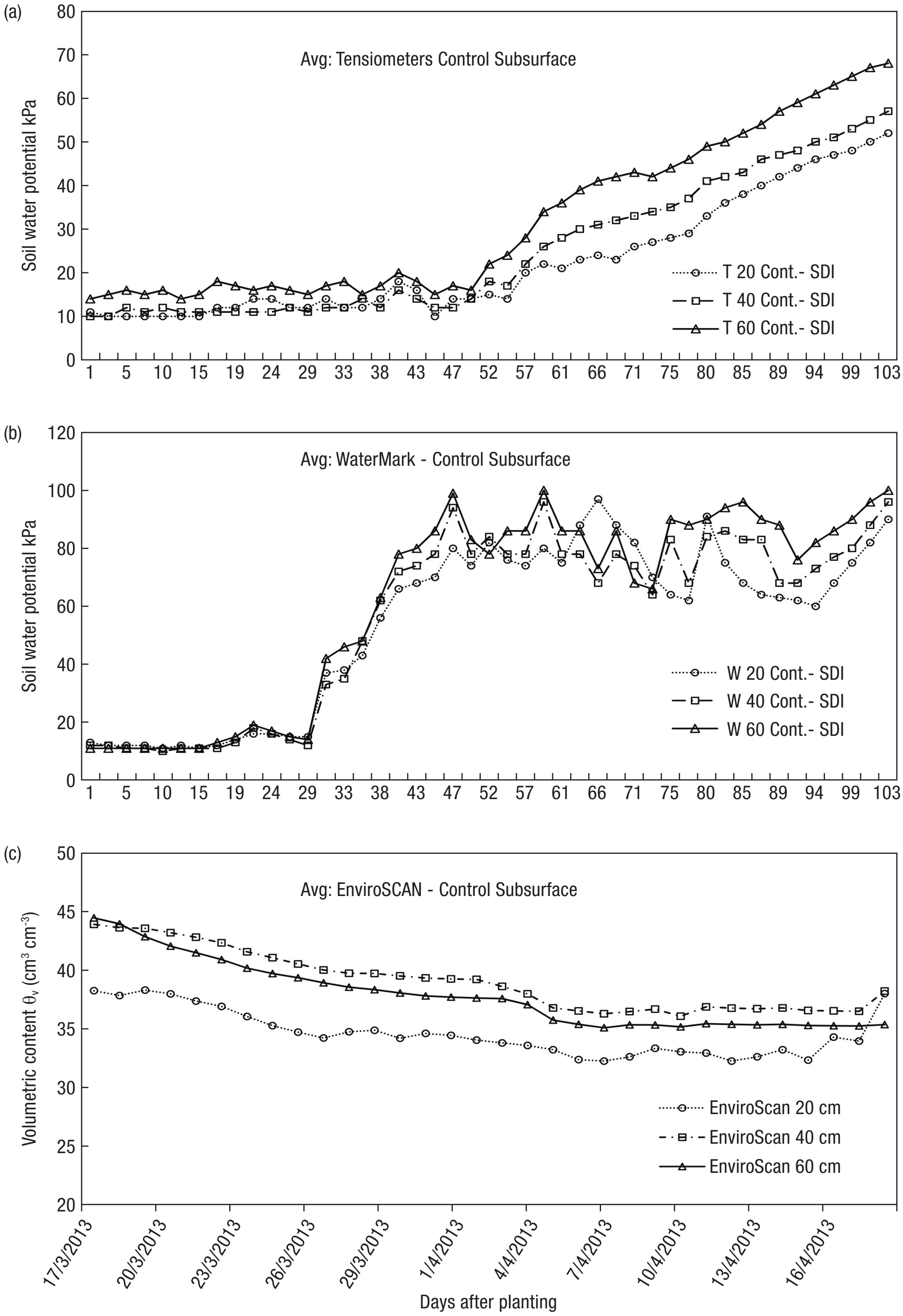

Figure 4. Soil water status measured by tensiometers (a), WaterMark (b), and EnviroSCAN (c) for the control subsurface.

curves for the three sensors followed a similar trend, but the moisture content values were different. Nonetheless, the EnviroSCAN probes remain a suitable tool for automatic irrigation scheduling and can be integrated with an automatic controller in irrigation systems. Hence, the soil moisture sensors are suitable for providing instantaneous information on the soil water status.

Irrigation management

The Hunter Pro-C and SmartLine automatic controller devices were effectively used for irrigation scheduling. These controllers can be adjusted to start a specific action based on a minimum irrigation amount, to prevent shallow watering and to customize performance for a specific plant.

The cumulative amounts of irrigation water added by SmartLine under the subsurface systems are presented in Table 2. The depths of water added (Dg)t for the three replicates were 518.2, 509.2 and 498.7 mm, with an average of 508.7 mm for SDI. Hence, the total water added per hectare was 2034.9 m^3/ha. There were no large differences between the replications throughout the growing season, which was expected because the same controller device was used for scheduling these replications.

Similarly, the cumulative amounts of irrigation water added by the Hunter controller under SDI are presented in Table 3. The depths of water added (Dg) t for the three replicates were 556.8, 545.2 and 566.6 mm for SDI, with an average of 556.2 mm, corresponding to 2224.8 m^3/ha. There were no large differences between the replications throughout the growing season, which was expected because the same controller device was used for scheduling these replications.

Table 4 shows the cumulative amounts of irrigation water added throughout the growing season for the control treatment under SDI. The total depths of water added (Dg)t for the three replicates were 687.8, 661.7

Table 2. Weekly cumulated irrigation depth (Dg)t for SmartLine subsurface system experiment.

Growth period (week)	Irrigation depth- Dg (mm)				Cumulative depth (Dg)t (mm)	Water added (m^3/ha)
	R_1	R_2	R_3	Avg.		
1	15.86	15.26	14.20	15.11	15.11	60.424
2	22.00	22.87	20.48	21.78	36.89	87.138
3	24.98	23.25	25.97	24.74	61.63	98.946
4	36.57	32.74	35.17	34.83	96.45	139.305
5	39.68	39.29	36.59	38.52	134.97	154.080
6	40.96	42.65	43.07	42.23	177.20	168.912
7	41.03	40.63	39.02	40.23	217.43	160.908
8	40.28	41.51	41.51	41.10	258.53	164.409
9	43.16	41.52	38.64	41.11	299.64	164.436
10	40.18	40.97	37.03	39.40	339.04	157.584
11	35.85	37.32	37.69	36.96	375.99	147.822
12	38.00	37.25	36.51	37.25	413.24	149.003
13	35.57	30.83	35.23	33.88	447.12	135.514
14	32.67	31.42	29.25	31.11	478.23	124.450
15	31.41	31.72	28.36	30.50	508.73	121.988
Sum	518.21	509.24	498.74	508.73		2034.9

R_1, R_2 and R_3 are replications 1, 2 and 3, respectively.

Table 3. Weekly cumulated irrigation depth (Dg)t for Hunter subsurface system experiment.

Growth period (week)	Irrigation depth- Dg (mm)				Cumulative depth (Dg)t (mm)	Water added (m^3/ha)
	R_1	R_2	R_3	Avg.		
1	16.72	15.56	17.39	16.56	16.56	66.234
2	25.59	22.91	24.62	24.37	40.93	97.491
3	24.32	27.16	26.13	25.87	66.80	103.485
4	35.95	38.62	40.15	38.24	105.04	152.963
5	43.10	40.15	43.53	42.26	147.30	169.039
6	47.67	48.14	45.78	47.20	194.50	188.784
7	42.48	40.79	42.90	42.06	236.55	168.222
8	45.54	45.54	44.19	45.09	281.65	180.371
9	45.11	41.99	46.90	44.67	326.31	178.667
10	45.84	41.43	44.96	44.08	370.39	176.307
11	39.74	40.14	38.17	39.35	409.74	157.403
12	40.57	39.76	41.38	40.57	450.31	162.281
13	34.49	39.42	39.80	37.90	488.21	151.614
14	34.81	32.40	36.19	34.47	522.68	137.871
15	34.86	31.17	34.52	33.52	556.20	134.066
Sum	556.80	545.19	566.60	556.20		2224.78

R_1, R_2 and R_3 are replications 1, 2 and 3, respectively.

Table 4. Weekly cumulated irrigation depth $(Dg)t$ for control subsurface experiment

Growth period (week)	Irrigation depth- Dg (mm)				Cumulative depth (Dg)t (mm)	Water added (m^3/ha)
	R_1	R_2	R_3	Avg.		
1	20.92	18.73	20.13	19.93	19.93	79.713
2	29.89	27.82	31.07	29.59	49.52	118.369
3	31.45	32.69	29.27	31.14	80.66	124.545
4	49.19	47.31	44.03	46.84	127.50	187.380
5	52.85	48.74	52.34	51.31	178.81	205.240
6	55.10	57.94	57.37	56.80	235.61	227.203
7	51.18	48.67	50.68	50.17	285.79	200.696
8	53.65	55.30	55.30	54.75	340.54	218.999
9	56.94	50.98	54.77	54.23	394.77	216.930
10	54.59	50.31	55.66	53.52	448.28	214.065
11	45.54	47.89	47.42	46.95	495.23	187.788
12	51.61	49.59	50.60	50.60	545.83	202.408
13	48.32	47.86	41.88	46.02	591.86	184.084
14	43.94	39.34	42.27	41.85	633.70	167.398
15	42.67	38.53	43.08	41.43	675.13	165.710
Sum	687.84	661.69	675.86	675.13		2700.53

R_1, R_2 and R_3 are replications 1, 2 and 3, respectively.

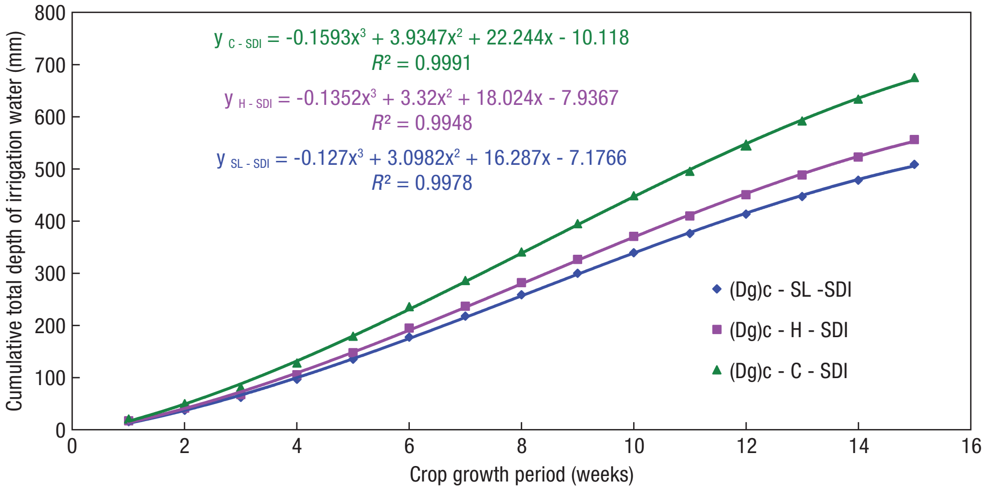

Figure 5. Comparison between the cumulative irrigation depths added by subsurface systems by using SmartLine (SL) and Hunter (H) and Control (C) systems.

and 675.9 mm for SDI, with an average of 675.1 mm. The total seasonal amount of water added was therefore 2700.5 m^3/ha. There were no large differences between the replications throughout the growing season, which was expected because the same ETr and Kc values were considered for the three plots.

Comparison of smart systems with control treatment

Figure 5 provides a comparison between the average depths of water added to the three treatments. The figure shows that the average irrigation depths added under the SmartLine, Hunter and control treatments were 508.8, 556.2 and 675.1 mm, respectively. These averages represent 50.9%, 46.3% and 34.8%, respectively, of the average amount (1035 mm) of water normally applied to tomato crops in the Riyadh area (MOA, 2012).

The control treatment received more water than the other two treatments, with reductions of 25% and 18% for the SmartLine and Hunter sensors, respectively. The differences for both treatments were significant according to a LSD test at the 0.05 probability level. It can be concluded, therefore, that the SmartLine and Hunter controllers significantly reduced water consumption compared with the control treatment (Fig. 5), and can thus provide reliable crop irrigation scheduling.

Agronomical characteristics of tomatoes

The ANOVA results for the tomato vegetative growth yield and fruit quality characteristics showed that the irrigation systems had significant effects in all of the investigated treatments. The average vegetative growth characteristics are given in Table 5. The characteristics for the Hunter treatment were significantly higher than those for the other treatments. In particular, the plant heights were 74.2 cm for the Hunter and 47.8 cm for the control treatment. Similarly, the number of branches, stems, fresh weight (FW), plant FW, leaf dry weight (DW), stem DW and plant DW were 8.5, 839, 230.6, 1069.6, 88.6, 49.8 and 138.5 g, respectively, for the Hunter treatment, compared with 3.2, 266.6, 86.2, 352.8, 37.2, 16.8 and 54 g for the control treatment. The vegetative growth characteristics for the SmartLine treatment were lower than those for the Hunter treatment, but higher than those for the control treatment.

Fruit yield components traits

Table 6 presents the average fruit yield components for the tomato plants growing under the different treatments. All of the fruit yield components for the Hunter treatment were significantly higher than those for the other treatments. For the Hunter treatment, the early yield (ton/ha), total yield (ton/ha), average fruit weight (g) and fruit number per plant were 54.1 and 88.6, respectively, compared with 39.6 and 64.5 for the SmartLine treatment. Early fruiting is a great advantage for growers because it increases market profits (Alexopoulos *et al.*, 2007). The average fruit weight (g) and fruit number per plant were 147.6 g and 30 for the Hunter treatment and 88.4 g and 24.7 for the control treatment, respectively. The higher number of fruit per plant in the Hunter treatment was due to the availability of adequate soil water status during the different growth stages. Irrigation is the single most important factor affecting tomato yield and fruit quality; stronger and healthier plants can produce higher rates of flowering, fruit set and ripened fruits.

The results in Table 7 show the differences in the amounts of water added to the tomato crops and the yields produced by the three irrigation scheduling methods. Table 7 also shows the IWUEs of the different irrigation methods and the water savings for these methods compared with local practices. The IWUE value for the Hunter treatment is the highest. The to-

Table 5. Averages of vegetative growth character for tomato plants for different treatments.

Main treatments	Plant height (cm)	No of branches	Leaf FW (g)	Stem FW (g)	Plant FW (g)	Leaf DW (g)	Stem DW (g)	Plant DW (g)
SmartLine controller	69.53b	5.73b	232.57c	152.90b	492.47b	49.10b	28.97b	93.17b
Hunter controller	74.17a	8.53a	839.00a	230.57a	1069.57a	88.63a	49.83a	138.47a
Control irrigation	47.76c	3.18c	266.58b	86.22c	352.8c	37.2c	16.8c	54c

FW: fresh weight. DW: dry weight. Values with same letters, within a particular column, are not significantly different according to a LSD test at 0.05 probability level.

Table 6. Averages of fruit yield components for tomato plants growing for different treatments.

Main treatments	Early yield (ton/ha)	Total yield (ton/ha)	Average fruit weight (g)	No. fruit per plant
SmartLine Controller	39.57c	64.53c	125.97b	25.50b
Hunter Controller	54.10a	88.56a	147.63a	30.00a
Control Irrigation	44.30b	72.58b	88.40c	24.70c

Values with same letters, within a particular column, are not significantly different according to a LSD test at 0.05 probability level.

Table 7. Comparison between irrigation water used efficiency (IWUE) for the two smart controller irrigation systems and saving water with different treatments

Main treatments	Water added		Total yield (ton/ha)	Total yield (kg/mm)	IWUE (kg/m^3)
	mm	m^3/ha			
SmartLine controller	508.73	2034. 90	64.53	126.84	12.68
Hunter controller	556.20	2224.78	88.56	159.22	15.92
Control irrigation	675.13	2700.53	72.58	126.20	10.75

mato yield and the amount of applied irrigation water in this treatment were 88.6 ton/ha and 2224.8 m^3/ha, respectively. Generally, these results are in line with those reported by Elmaloglou *et al*. (2010) and Al-Omran *et al*. (2010). SDI increases the yield and WUE of tomato crops and reduces the amount of applied irrigation water by creating a good distribution of water around the roots.

In summary, the data presented in Table 7 indicate that the Hunter Pro-C system allows further water-saving and higher yield if compared with the other scheduling methods, and thus has the highest IWUE.

The examined treatment with Hunter under SDI has shown notable differences in both tomato quality production and irrigation water use efficiency (saving 17% of total irrigation water). To conclude, under arid conditions, efficient modern electrical controllers for smart irrigation systems such as Hunter should be applied to maintain water rationalization as well as economic benefits.

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