ASSESSMENT OF SMART IRRIGATION CONTROLLERS UNDER SUBSURFACE AND DRIP IRRIGATION SYSTEMS FOR TOMATO YIELD IN ARID REGIONS

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Abstract

Two types of Smart irrigation controllers (SIC) for reducing irrigation water are studded under Saudi Arabia’s present water crisis scenario. These are based on evapotranspiration (ET) which are promising tools for scheduling irrigation and quantifying water required by plants to achieve water savings. The purpose of this study is to evaluate the effectiveness of these technologies, i.e. SmartLine and Hunter on irrigation amount applied, and compared with conventional irrigation scheduling methods as a control treatment. These two types of smart irrigation were implemented and tested under drip irrigation (DI) and subsurface irrigation (SI) for tomato crop (Nema tomato cv.) in arid region. The results showed that there are significant differences in the amount of applied water and the yield for the three irrigation scheduling methods.

The obtained indicated that each one mm water depth applied by Hunter Pro-C, SmartLine (SL 1600) and control systems to the tomato crop produced 126.84 kg/mm, 159.22 kg/mm and 107.5 kg/mm under subsurface drip irrigation respectively, while under surface drip system were 68.67 kg/mm, 90.72 kg/mm and 107.18 kg/mm respectively. Generally, it can be noted from the data analysis that Hunter Pro-C system save water and produced more yield with the highest water irrigation efficiency (IWUE) compared with the other irrigation scheduling methods. In
addition, the results indicated that subsurface irrigation system gave the highest yield and IWUE compared to the surface drip system.

**Keywords:** Smart irrigation; ET controllers; drip irrigation, subsurface drip irrigation systems; irrigation water use efficiency; arid region, tomato yields.

**Introduction**

Improvements for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions. Therefore, use of new irrigation technologies in agriculture have aimed at increasing crop production, and in these respect new developments in irrigation technologies are of great importance. With increasing demands on limited water resources and the need of minimizing adverse environmental consequences of irrigation, micro-irrigation and smart irrigation technology will undoubtedly play an important role in the future of the Saudi Arabia agriculture. It provides many unique agronomic, water and energy conservation benefits that address many of the challenges facing irrigated agriculture.

Wang et al., (2009) reported that the, micro-irrigation methods, such as drip irrigation, were adopted for field experiments for food crops. Hassanli et al., (2009) compared three irrigation methods, drip, subsurface and furrow irrigation. Results showed that the maximum amount of water with highest water use efficiency (WUE) was provided through subsurface irrigation system. Khairy et al., (2009) found that the subsurface irrigation gives the highest yield when compared to drip irrigation system for tomato in sandy soil. Al-Omran et al., (2010) concluded that the subsurface drip irrigation increased the yield and WUE of the tomato crop resulted in the saving of applied irrigation water by creating a good moisture distribution in the root zone depth.

Irrigation scheduling remains a reliable technique for applying the needed amount of water on time. Automated irrigation systems based on crop needs of water are providing maximum possible efficiency of water use (Munoz-Carpena et al., 2003; Munoz-Carpena et al., 2005 and
Munoz-Carpena and Dukes, 2005). There are three methods for matching irrigation with crop water requirements: the weather-based methods using evapotranspiration, ET (Allen et al. 1998), the soil water-based methods using soil moisture sensors (Evett 2008) and the soil–water-balance calculations and plant stress-sensing techniques (Jones 2004). The Smart Water Application Technology Committee of the Irrigation Association (IA, 2011) defines ‘Smart controllers’ as those technologies which estimate or measure depletion of soil moisture in order to replenish water as needed. Vellidis, et al, (2008) conducted a study using intelligent devices to measure soil moisture and soil temperature. They pointed out that the intelligent sensors can be integrated with intelligent irrigation techniques to conserve water and time.

The smart irrigation controllers SIC integrate many disciplines to produce a significant improvement in crop production and resource management (Norum and Adhikari 2009). Mayer et al., (2009) found that SIC reduced irrigation by 6.1%; and it was found that 56.7% of the sites were responsible for a significant decrease in irrigation application, while 41.8% were responsible for a significant increase. Davis et al., (2010) demonstrated that that the SIC applied approximately half of the irrigation calculated for the theoretical requirement for each irrigation event, on average, irrigation adequacy decreased when the SIC were allowed to irrigate any day of the week. Al-Ghobari and Mohammad (2011) reported that the initial results indicate that up to 25% water saving by intelligent irrigation system (IIS) compared to control method, while maintaining competing yield. Davis and Dukes (2012) found that SIC can match irrigation application with seasonal demand and in particular reduce irrigation in the winter when plant demands are dramatically reduced. In addition, they point out that when SIC are applied to sites, irrigating at levels less than plant demand, those SIC will likely increase irrigation. Mohammad et al. (2013) revealed that the two-year field study and using the IIS for irrigation water scheduling, it was found that the IIS offered a significant advantage in managing the irrigation of
tomato crops in both seasons under severely arid conditions. Consequently, the results show that the IIS had significant effects on water use efficiency (WUE) and irrigation water use efficiency (IWUE). The IIS technique conserved irrigation water by 26% compared to the amount provided by the control method.

Adoption of modern water-saving technology is often cited as a key to increasing water use efficiency while maintaining current levels of production (Green et al., 1996). The main aim of these techniques has been to achieve efficient water delivery and high productivity while minimizing water (Acar et al., 2010). Though, this technology has not been tested with field crop in a hyper arid region such as Saudi Arabia. The main objective of this study was to determine the effectiveness of two SIC i.e. SmartLine and Hunter in their ability based on the amount of irrigation applied to conserve water use for tomato crop irrigation in arid region under drip and subsurface irrigation systems.

Materials and Methods

Site description

This study was performed at the experimental farm of the College of Food and Agriculture Sciences of King Saud University, Riyadh, at 24°43´N latitude, 46°43´ E longitude and 635 m altitude during the spring season of 2013. Generally, the climate in this region is classified as arid, and the climatological data, such as temperature, relative humidity, rain, solar radiation, and wind speed were measured at the experimental site during the course of the study. The weather station was installed at the field site and used to measure the climate parameters that were used to compute evapotranspiration (ETo). The distance from the weather station to the sample plots was less than 10 m. Two types of smart irrigation controllers (SmartLine SL 1600 and Hunter pro-c) were installed at tomato crop fields. Each system was programmed in situ, taking into account the crop type and environmental conditions of the area.
Experimental layout and irrigation treatment design

The study site was 1800 m$^2$ (60×30m) has been located for the experiments, and divided into three fields separated with buffer zones of 5 m wide (Fig.1). Two of these fields are divided into six plots, and the third one is divided into two plots as control for comparison proposes. Each plot size was 7 m × 10 m (70 m$^2$). Three plots from each field were irrigated with subsurface (SI) and another three with drip irrigation (DI). The total plots of the experiments were 14, six (1 - 6) were controlled and irrigated automatically by Smart line controller, while the other six (7 - 12) were controlled and irrigated automatically by Hunter. While plots 13 and 14 managed manually in the two treatments, SI and DI respectively as control treatment (fig. 1).

The field was cultivated with tomato crop (Nema tomato cv.). Two of the three fields were irrigated automatically by modern electrical controllers, via smart irrigation controllers (SIC) namely SmartLine, SL-1600 (SL) and Hunter Pro-C$^2$ (H) respectively. This system is not considered the best system, but it was inexpensive and available on the local market. Each was sub divided into two plots, SI and DI irrigation systems, and all plots were provided with seven parallel drip lines, 10 m long, and one meter a part (fig. 1). The third plot was irrigated manually with irrigation control system (ICS) based on ETc values using climatological data from the weather station. Reference evapotranspiration (ETo) was computed for a hypothetical reference crop according to the methodology of FAO paper no. 56 (Allen et al., 1998). The soil type in the study area was sandy loam, and some physical properties of the experimental field soil are presented in Table (1). This table shows that the soil present at the field site consist of 15.24% clay, 13.94% silt and 70.82% sand.

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1The use of the trade name does not imply promotion of this product; it is mentioned for research purposes only.
Both the SI and DI systems consisted of 16 mm inside diameter separated with 1m distances and mounted with 20 drippers. Drip lines are mounted with emitters of a nominal discharge 3.5 L/h at a design pressure of 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 flush line and flush valve at the distal end of the plot. These lines for both (SI and DI) were provided with polyethylene laterals fitted with emitters. The laterals were laid on leveled ground, and connected to PVC sub main pipes, which were connected to galvanize steel main line. The main lines were connected to the pump unit, equipped with pressure regulators, and flow meters to measure the amount of water added in each plot irrigation event.

The drip system was evaluated in the field according to the methodology of ASABE Standard, S346.1 (2007). The smart irrigation controller is required a complete database for each station (or “zone”) to be controlled. Every controller must be carefully observed and monitored after initial installation for the best results. Generally, most systems require adjustment, at the station level, for some time after installation to provide ideal results. Evaluation tests were conducted by checking the performance index values under the operating field conditions. These evaluation values must be within acceptable limits with good water distribution uniformity (over 90%).

**Smart controller’s installation and setup**

The SIC was installed according to the manufacturer’s instructions in the field for the planned experiments. It can be customized by station (or “zone”) for specific plants, soils and drip types.

Auto adjust operation requires that the SmartLine controller is provided with the latitude location of the site. The other data required are auto adjust data such as irrigation system type; plant type, soil type and other information to be able calculate run times for each zone. Irrigation
system type is set as drip irrigation, which apply 1.1 inches per hour (2.794 cm/hr). Then the type of plant to be watered by each zone must be specified in the SmartLine controller. The system provided with a list of plant types to be selected. In our study the native plant zone is assigned due to its flexibility in adjusting the percentage ranging from 10 to 300. In addition, soil type and degree of slope are also required for SmartLine controller to automatically calculate the maximum length of a zone run time before pausing watering for a calculated period to allow the water to soak into the soil. Therefore, sand type was selected from the three options (clay, loam and sand).

The Hunter controller based on ET System which uses sensors to determine the local “evapotranspiration” (ET) rate of tomato crop installed in the field, and ET Module interface enclosure, installed next to the irrigation controller. This type of system uses digital electronic controllers, modules, and its platform can be wired to an ET module. Then the ET sensor applies the command of initiating and stopping irrigation event to the individual fields (zones) of irrigation. The IIS automatically calculates crop evapotranspiration (ETc) for local microclimates based on the modified Penman equation of FAO paper no. 56 (Allen et al., 1998) and creates a scientific program that it downloads to the controller.

Hunter controller system was preset to operate with 150% of ET. However, this can be adjusted (in 1% increments) from 10% to 150%. The higher the percentage, of the "wetter" the system will run. The adjustment Hunter controller system is applied equally to all stations, which are further modified by their individual settings (Plant, Site Information, and irrigation types). This factor may compensate for non-ideal mounting conditions, where the sensor cannot be placed according to ideal specifications.

**Field operation and observations**
The field allocated for SI irrigation has been excavated to a depth of 15 cm below the soil surface to accommodate subsurface irrigation pipes. The sequence steps of field preparation were completing installation of the rest of irrigation network, which consist of valves, flow meter and pressure meters. Tomato plants (*Nema tomato cv.*.) were transplanted into the fields on February 7, 2013. The seedlings were planted in a single row in each bed, with a row spacing of 1 m and an interplant space of 0.5 m per row. Other cultivation practices were performed following the scheduled program of tomato crop. Harvest-ripe fruits were manually picked up and weighed twice a week, started on 25 April, and continued until the end of experiment.

Fruit yield and its components were evaluated in eight plants from the central plot rows during the harvest period. Other agronomic parameters, such as total fruit yield, were recorded for each plot to obtain the gross yield (t ha\(^{-1}\)).

To calculate \(\text{ET}_c\) and irrigation water requirement of tomato, daily \(\text{ET}_0\) values were first determined by the meteorological station and then were multiplied by crop coefficients and water application efficiency. Based on the area of the field and the discharge rate from the drippers (3.5 l/h), the required water quantity per event and actual operation time required could be determined. Accordingly, the actual operation time required was then calculated. The irrigation system was turned on and off in control experiments manually in CIS plots. Furthermore, the irrigation water depths (\(D_g\)) and cumulative depths added to the tomato crop under the two the (SIC) and (ICS) irrigation treatments were monitored by flow meters and were recorded through the growing season.

**Water use efficiency**

Irrigation water use efficiency (IWUE) was calculated as the ratio between the total fresh yield (Y) and the seasonal applied irrigation water (Dg)c as given by Michael (1978). The IWUE was calculated by using Equations 1.
\[ \text{IWUE} = \frac{Y}{(Dg)_c} \]  
(Michael, 1978)  

Where, in these equations, \( Y \) is the fresh yield (kg m\(^{-3} \)), and \((Dg)_c\) is the amount of seasonally applied irrigation water (mm).

The mature fruits were harvested once or twice a week, and the plant height (cm), branch number, fruit length (cm), fruit diameter (cm), fruit shape index (length/diameter), average fruit weight (g), and total yield (kg.m\(^{-2} \) and ton/h\(^{-1} \)) were measured for each plot at each harvest.

**Statistical analysis**

The experimental design was a split plot and analysis of variance (ANOVA) was established to determine any statistically significant differences. Computer program (SAS, 2008) are used to determine treatment effects for total vegetative growth, fruit yield components, fruit quality traits yield and IWUE. The means are separated through a revised least significant difference (LSD) test at the \((p < 0.05)\) level was used to compare treatment means (Steel & Torrie, 1980).

**Results and Discussion**

**Irrigation management**

The results of the implementation of three different scheduling techniques (Hunter-Pro C and SmartLine controllers and control treatment) under two irrigation systems (surface drip and subsurface drip systems), which were assigned to each scheduling system. These system scheduling techniques (Hunter-Pro C and SmartLine controllers) were equipped with special options, such as the addition more or less water depending on the needs of the plant. The water quantities were monitored and recorded.

Cumulative irrigation water depths \((Dg)_c\) was added by SmartLine under subsurface and drip systems are presented in table (2). This table shows that the weekly cumulative irrigation
water added [(Dg)c] throughout crop growing period for SI and DI. The depths of the water added for the three replicates are 508.23, 511.63 and 506.40 mm for SI, and 571.76, 569.54 and 564.66 mm for DI. It is clear that there are no significant differences among the replications throughout the growing season. This was expected because the same controller device is used for scheduling for these replications.

From this table, the average amounts of irrigation water applied by SI and DI irrigation were 508.75 and 568.65 mm, respectively. These averages are less than the average amount of irrigation water practiced by the framers in the area. Generally, the irrigation practice in Riyadh area is at least 720.2 mm, which are 41.6% and 26.7% more than DI and SI respectively. This result also shows that the DI system applied more water than SI by 11.8%. This was expected since the subsurface irrigation system is less susceptible to evaporation than drip irrigation.

From the data of this table, a comparison between the depths of water added by SI and DI systems using SmartLine system are plotted in Figure (2). It is clear from this figure that the cumulative irrigation depth added by DI throughout the growing season was higher than the SI system. However, the differences in both irrigation methods are considered significant.

Similarly it is noted that the cumulative irrigation water depths (Dg)c was added by Hunter controller under SI and DI and are presented in table (3). This table shows that the weekly cumulative irrigation water added [(Dg)c] throughout crop growing period for SI and DI. The depths of the water added for the three replicates are 556.18555.99 and 556.43 mm for SI, and 628.37, 625.51 and 627.40 mm for DI. It is clear that there are no significant differences among the replications throughout the growing season. This was expected because the same controller device is used for scheduling for these replications.

From this table, the average amounts of irrigation water applied by SI and DI irrigation were 556.2 and 627.09 mm respectively. These amounts are less than the amount of irrigation
water practiced by the framers in the area. Generally, they are less than the irrigation practice in Riyadh area by 46.26% and 39.41% for SI and DI irrigation respectively. This result also shows that the DI system applied more water than SI by 11.30%. This was expected since the SI is less susceptible to evaporation compared to DI.

A comparison between cumulative depths of water [(Dg)c] added by SI and DI using Hunter system are shown in figure (3). It is clear from this figure that the cumulative irrigation depth added by DI throughout the growing season was higher than the SI system. However, the differences in both irrigation methods are considered significant.

**Comparison of intelligent systems with control treatment**

Weekly Irrigation water added (Dg) and cumulative depth (Dg)c in first season for control subsurface and drip experiments are presented in figure (4). This figure shows that the irrigation depths added under SI and DI systems are 675.16 and 734.64 mm respectively.

Comparison between depths of water added by SI and DI systems under control treatment are shown in figure (4). These figures points out that the values of the two treatments are close enough. This due to the fact that both systems are scheduled based on ETc calculations. These values are higher than the mentioned values 508.75 (Fig. 2) and 556.20 mm (Fig. 3) obtained by SmartLine and Hunter SI respectively. It means that the control treatment is higher with 24.65% and 17.62% than SmartLine and Hunter SI respectively.

Similarly the water added to the control treatment is higher than that mentioned values 568.65 (Fig. 2) and 627.09 mm (Fig. 3) obtained by SmartLine and Hunter DI, respectively. It means that the control treatment is higher with 22.96% and 14.64% than SmartLine and Hunter DI, respectively. It could be concluded from these results that the SI under SmartLine controller is applied less water compared to other treatments.
These findings are clear in the figures (5 and 6) which describe the depths of water added by SI and DI using SmartLine and Hunter and Control treatments.

**Agronomical characteristics of tomato**

Results of analysis of variance for tomato vegetative growth yield and fruit quality characters as affected by irrigation systems showed that there is a significant effects for irrigation systems on all studied traits.

**Vegetative growth traits**

The averages of vegetative growth characters are given in table (4). From this table it can be observed that all vegetative growth characters for Hunter controller under SI are significantly higher than other treatments. Such as plant height is 74.17 cm for Hunter controller under SI, while it is 47.76 cm for control treatment under SI. Similarly, the number of branches, leaf fresh weight, stems fresh weight; plant fresh weight, leaf dry weight, stem dry weight and plant dry weight are 8.53, 839, 230.6, 1069.6, 88.6, 49.8 and 138.5g respectively for Hunter controller under SI treatment. While, they are 3.2, 266.6, 86.2, 352.8, 37.2, 16.8 and 54g for control treatment under SI.

**Fruit yield components traits**

Fruit yield components for tomato plants growing for different treatments in first season are presented in table (5). This table shows that Hunter controller under SI significantly increase all fruit yield components traits is the higher, compared to the two systems of irrigation. The averages of fruit yield components for tomato plants are given in table (5). From this table can be observed that all the fruit yield components for Hunter controller under SI are significantly higher than other treatments. For Hunter controller under SI the early yield (ton/ha), total yield (ton/ha),
average fruit weight (g) and fruit number per plant are 54.10, 88.56, 147.63 and 30 respectively, and they are 23.37, 39.05, 77.63 and 11.03 for SmartLine controller under DI.

**Fruit quality traits**

Fruit quality characters for tomato plants growing for different treatments are presented in table (6). This table shows that Hunter controller under SI system had the highest values for fruit length and fruit diameter traits, followed by Hunter controller under DI. However; the lowest fruit length and diameter were reflected by control under SI. On the other hand, the results clarified that the highest values of the dry matter (%), total soluble solid (TSS %), vitamin C (g/100 g FW) and total acidity (TA %) were reflected by SmartLine controller DI. While, the lowest values was with the four traits control under DI.

The averages of fruit quality characters for tomato are given in table (6). From this table it can be observed that the fruit length and fruit diameter for Hunter controller under SI is higher than the corresponding characters in other treatments. The fruit length and fruit diameter are 5.73 and 5.8 cm for Hunter controller under SI, while they are equal to 3.66 and 3.60 for control treatment under SI respectively. Meanwhile, the dry matter and total soluble solid for SmartLine controller under DI are higher than different treatments. The dry matter, total soluble solid and total acidity are 6.43, 6.57, and 0.61 for SmartLine controller under, and equal to 3.12, 3.14, and 0.32 for control treatment under DI respectively.

**Irrigation water use efficiency**

Table 7 illustrates the comparison between IWUE for the tow smart controller irrigation systems and the saving of water with different treatments and with local practices on tomato water use efficiency during the growing season. Through analysis of this table, it is found that the
value of IWUE is higher in the Hunter controller under IS treatment. The tomato yield in the case of Hunter controller under IS treatment, were 88.56 ton h\(^{-1}\) for season. Moreover, the amounts of applied irrigation water were 5562 m\(^3\) h\(^{-1}\) for growing (Table 7). In contrast, the smallest amount of irrigation water used was 508.75 mm in case of SmartLine controller under IS, while the largest amount applied was 734.64 mm in the control under DI treatment.

The results in Table (7) showed that there were differences in the amount of water added to the tomato crop and the produced yield between the three irrigation scheduling methods. But, the data indicated that each one mm water depth applied by SmartLine, Hunter and control systems to the tomato crop produced 126.84 kg/mm, 159.22 kg/mm and 107.5 kg/mm under subsurface drip irrigation respectively, while under surface drip system were 68.67 kg/mm, 90.72 kg/mm and 107.18 kg/mm respectively. However, the average of water depth applied by the local farmers in the same region of Riyadh during the previous ten years (MOA, 2012) for tomato crop under surface drip irrigation was 16.15 kg/mm. Generally, it can be noted from the data analysis that Hunter Pro-C system save water and produced more yield with the highest water irrigation efficiency (IWUE) compared with the other irrigation scheduling methods (Table 7). In addition, it can be noted that SmartLine system has the lowest values compared to Hunter system as shown in table (7). Also, the results indicated that subsurface irrigation system gave the highest yield and IWUE compared to the surface drip system. Therefore; it can be depicted from these results that the irrigation water was used most effectively in Hunter controller under subsurface irrigation treatment.

**Conclusion**

A study was conducted in Riyadh, Saudi Arabia with the purpose of evaluating the effectiveness of two smart systems, based on the amount of irrigation applied for improving water use is critical for sustainability of irrigated farming by DI and SI systems in arid regions.
The results showed that there were differences in the amount of water added to the tomato crop and the produced yield between the three irrigation scheduling methods. The results reveal that the plant growth parameters and water conservation were significantly affected by Hunter controller under SI.

This result indicated that the water was used most effectively by Hunter controller under SI. Therefore, applying irrigation by this technique provides significant advantages in terms of both crop yield and IWUE. In addition, Hunter controller conserves 23% of the total irrigation water compared to the control treatment, and simultaneously generates higher total yields.

The methods presented in the study make significant headway towards that goal. Smart irrigation controllers hold promise for efficient irrigation by conserving water while maintaining acceptable quality and increase yield. Finally, it should be noted that performance of these smart irrigation technologies depends on studies summarized here; ET controllers have the potential for up to 50% water savings compared to compare to conventional irrigation scheduling methods. Hence a good overall tomato crop management program should be established and an efficient irrigation system maintained in order to obtain the full benefit of smart irrigation technologies.

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