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INTELLIGENT IRRIGATION IN VEGETABLE CROP (TOMATO): NOVEL APPROACH FOR WATER RESOURCE USE OPTIMIZATION

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ABSTRACT

Field experiments have been conducted in King Saud University, Riyadh-Saudi Arabia to study the weather-based irrigation controllers (WBICs) affecting agronomical characteristics and water use of irrigated. The assessed WBICs technologies were Weathermatic SL1600 and Hunter pro C controllers under subsurface drip irrigation system. The study investigated the effect of these technologies and its suitability for agricultural applications. The main results in this study can be summarized as the WBICs had significantly affected the tomato yield, water use efficiency and water savings. The WBICs could save irrigation water by 32.4 % and increased water use efficiency greatly up to 50.8 %, while maintaining competing yield as compared to a time-based irrigation schedules (control). Furthermore, the agronomical characteristics (vegetative growth, fruit quality and fruit yield traits) confirmed the priority of the WBICs when they compared with various time-based irrigation schedules.

Keywords: subsurface drip irrigation, water use efficiency,

INTRODUCTION

Smart irrigation system is referred to various types of controllers that have the capability to calculate and implement irrigation schedules automatically and without human intervention. The Irrigation Association(www.irrigation.org) defines “smart controllers” as controllers that reduce outdoor water use by monitoring and using information about site conditions (such as soil moisture, rain, wind, slope, soil, plant type) and applying the right amount of water based on those factors. Ideally, smart controllers are designed to use site-specific information to produce irrigation schedules that closely match the day-to-day water use of plants and landscapes/crops. Intelligent or smart irrigation technologies were regarded as a promising tool to achieve landscape water savings and reduce non-point source pollution.

Smart irrigation controllers include (i) evapotranspiration (ET) based irrigation controllers, (ii) Soil water sensor based irrigation controllers. In a soil water sensor based irrigation controllers, data from soil moisture sensor is used to allow or bypass timed irrigation events. Evapotranspiration (ET) based irrigation 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 (Dukes *et al.,* 2005). Standalone controllers use sensors installed on-site to measure weather site conditions and then calculate real-time ET_o based on the data collected. The sensors collect readings at intervals anywhere from every second to every fifteen minutes and then a daily ET_o is calculated from those values (Dukes *et al.,* 2005).

In Signal-based controllers, a wired (phone) or wireless (cellular or paging) communication is utilized to receive ET_o data. 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 ET_o value, and then broadcast the value directly to the controller each day (Dukes *et al.,* 2005). Historical-based controllers depend on historical ET_o information for the area. Typically, monthly historical ET_o 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 ET_o from historical trends (Dukes *et al.,* 2005).

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. Davis and Dukes (2012) summarize and review outcomes of ET controller research in Florida. They found that ET controllers could 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 ET controllers are applied to sites irrigating at levels less than plant demand, those controllers will likely increase irrigation. The ET controllers could potentially produce annual savings of 42% when compared to a time-based irrigation schedule that replaces the net irrigation requirement without considering real-time rainfall and still maintain good turfgrass quality (Davis *et al.,* 2009). The new intelligent irrigation system was under evaluation at the trial farm in Dookie, Egypt and initial results indicated up to 43% (average 38%) water saving over conventional irrigation control methodologies (Dassanayake *et al.,* 2009).

The objective of this study was to evaluate the suitability of two types of smart irrigation techniques for agricultural applications under subsurface drip irrigation system as compared to various time-based irrigation schedules (control).

MATERIALS AND METHODS

Experimental Site

The study was conducted at educational farm of King Saud University, Riyadh- Saudi Arabia (24° 43' N latitude, 46° 43' E longitude and altitude of 635 m).The continental climate of the region was described as semi-arid, with an average annual precipitation of 100 mm. The climate parameters during the growth period of tomato crop are summarized in table 1. The soil profile of the experimental site in the upper 0–60 cm soil was, well-drained sandy loam texture composing of 68.81% sand, 15.43% silt and 15.76% clay, with an alkaline pH 7.3, EC 2 dS m^{-1}, $CaCO_3$21%, HCO-3 4.6%. The average soil water content at field capacity from surface soil layer down to 60 cm depth at 20 cm intervals was 15.97 % and the permanent wilting point for the corresponding depths was 6.13% respectively. Some other physical and chemical properties of the experimental soil are displayed in tables 2 and 3.

Table 1: The climate parameters during the growth period of tomato crop

Month	Tmax (c°)	Tmin (c°)	RH_a %	Rainfall mm	SR 10^4W^{-2SR}	WS (m/s)	ETo $mmday^{-1}$
February	17.38	16.15	34.15	0.00	39.23	5.47	4.30
March	23.08	22.27	25.07	0.01	48.93	5.25	4.86
April	27.86	26.31	30.74	0.22	43.71	6.59	5.65
May	34.54	30.25	24.17	0.15	45.81	5.63	6.20

Tmax, Tmin = maximum and minimum temperature; RH_a= average relative humidity; WS= wind speed; SR =solar radiation; and ETo = Evapotranspiration.

Table 2: The physical filed properties at different soil layers

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

Table 3: The chemical filed properties at different soil layers

Soil depth (cm)	pH	EC ds/m	Cations meq/l				Anions meq/l			$CaCO_3$%
			Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_{-3}	Cl^-	$SO4^{2-}$	
0-20	7.2	2.0	15.3	4.5	6.5	0.5	6.8	10.0	8.6	26
20-40	7.5	1.3	6.5	2.6	3.7	0.4	3.3	5.3	4.0	24
40-60	7.3	2.7	11.3	9.0	6.9	0.9	3.7	11.5	8.9	13

Site Description and Equipment Used

The site area (40×25 m) was prepared, leveled and then divided into three main fields separated with five meter as buffer zones for irrigation pipes and control wire purposes. Each field was subdivided into three plots separated with buffer zones of 1.5 m to reduce environmental influences between them, length and widths of these plots were 10 and 7 m, respectively. Thus, the area of the plot was 70 m^2. At that time, an extensive survey on electronic controller devices and irrigation systems components was executed and the most appropriate of them were chosen for the local conditions. Two types of weather-based irrigation controllers (WBICs), namely Hunter Pro-C and Weathermatic SL1600 which are available on the local market were selected for this study. The necessary hardware (weather station, water pump, irrigation systems components, and more) were also purchased. The WBICs were then programmed using the manuals provided by the manufacturers according to site-specific conditions. The plots in first and second fields were irrigated and controlled automatically by Weathermatic SL1600 and Hunter Pro-C controllers, respectively. While the plots in third field were irrigated and controlled manually by standard time-based controller through ET estimates downloaded daily from a nearby automated weather station (fig.1).

Fig 1: ET controllers after installation and set-up

Irrigation Requirement

The Tomato plants in control field were irrigated three days/week by different amounts of water according to ET values acquired from an automated weather station (Davis Cabled Vantage Pro2 Plus with Standard Radiation Shield) located within 10 m of the experimental site. The actual operation time required for control treatment was then determined using equation1.

$$T = \frac{ET_o \times K_c \times A \times P_w}{Ea \times (1 - LR) \times Q_s} \qquad Eq.1$$

where T is the actual operation time required (min), ET_o is the reference evapotranspiration (mm day^{-1}), Kc is the crop coefficient, A is the plot area (m^2), P_w is a wetted area percentage (%), Ea is the application efficiency (%), LR is the leaching requirements (%) and Q_s is the discharge from the irrigation system (lit/min).

Water Use Efficiency

The water use efficiency (WUE) were calculated as total marketable tomato yield divided by the seasonal irrigation applied water (Howell, 2001), using equation 2.

$$WUE = \frac{\text{Yield}\,(\text{kg})}{\text{Applied water}\,(\text{m}^3)} \qquad \text{Eq.2}$$

Cropping Details

Nema tomato cv. (Hybrid tomato cultivars recommended for cultivation in exposed field from Golden Valley Seed Company, USA) was used in this experiment. The chemicals and pesticides were applied as necessary identically to all plots. Fertilizers were divided and delivered with the irrigation water in all treatments during the growing growth. Total supply in N, P_2O_5, K_2O, C_aO and , M_g O were respectively 150, 100, 350, 80 and 75 kg/ha.. All treatments plots received the same amount of fertilizer .The crop was harvested after 105 days in 2014 (on 22 May).

Agronomical Characteristics

Two months after transplanting, random samples of three plants from each sub-plot were taken to measure vegetative growth traits (plant height, No. of primary branches/plant, stem fresh weight, plant fresh weight, stem & plant dry weight). Leaf samples were collected, washed in distilled water and dried at 70°C in forced air-oven until the weight became constant (48-72 hours) and the dry matter contents were calculated. The same thing with regard to fruit yield components, where fruit number per plant, average fruit weight/plant and total yield were determined. The fruit quality traits were also determined, where five fruit samples were collected, juiced, and filtered for measuring fruit content of total soluble solids (TSS, %), ascorbic acid (mg/100g FW) , and titratable acidity (TA, %) (AOAC, 1995).

Statistical Design

The experimental design was a split plot and the least significant differences method (LSD) at 0.05 level was employed to evaluate the statistical effect of irrigation treatments and agronomical characteristics results. The treatments were established, T1 through T3, replicated three times for a total of nine plots. The SPSS-18 statistical package was used to evaluate the statistical differences between treatment means.

RESULTS AND DISCUSSION

Weather- Based Irrigation Controllers

The weather- based irrigation controllers (WBICs) have been used to schedule irrigation in tomato crops under subsurface drip irrigation system (SSD) using Wheathermatic SL 1600 and Hunter-Pro C controllers. Hence, the irrigation-scheduling program has been executed automatically based on local climate conditions collected by the weather controllers' sensors and processed by the intelligent system. The total amount of irrigation depths added to each group of replications (R1, R2 and R3) separately by Weathermatic-subsurface drip (W-SSD), Hunter- subsurface drip (H-SSD) and Control-subsurface drip (C-SSD) treatments were 386.26, 388.83 and 384.86mm; 378.20, 378.08 and 378.37mm; 565.89, 557.88 and 555.88mm, respectively (tables 4, 5 and 6). It can be deduced from these results that quantity of applied water had no statistical significance amongst the replications and most water savings were achieved in the plots irrigated by H-SSD followed by W-SSD when they compared with C-SSD (control treatment). This was expected where the dynamic irrigation scheduling for each group of replications was done by the same controller. Comparing accumulative irrigation depths of W-SSD and H-SSD with C-SSD during the crop growth period as seen in figure 2 showed that their values were close in the initial stages of the crop and get considerable differences in mid and late season stages. The curves also showed that both weather-based irrigation controllers (W-SSD and H-SSD) applied less water than standard time-based controller (C-SSD), where the average water depths applied by W-SSD and H-SSD were 386.67 and 378.20 mm, respectively as compared to C-SSD (559.88 mm), which is a difference of 173.21 and 181.68 mm, respectively. In other words, the highest overall water savings, averaging 32.4 %, was obtained from H-SSD treatment; this was followed by W-SSD treatments with averaging 31%, as compared to C-SSD. This could be due to the differences in runtimes, irrigation frequencies and the number of irrigation events bypassed under W-SSD and H-SSD systems.

Table 4: Weekly irrigation depth added to the replications by W-SSD

Growing period (Week)	**Irrigation depth by**				**Cumulative depth**
	(R_1)	**(R_2)**	**(R_3)**	**Average**	**Avg.(mm)**
1	10.16	8.69	8.81	9.22	9.22
2	11.42	10.24	10.37	10.68	19.90
3	16.47	16.16	13.64	15.42	35.32
4	21.10	18.57	22.03	21.83	57.14
5	21.55	19.18	24.37	22.66	79.80
6	23.07	21.57	24.39	23.35	103.15
7	24.11	23.67	25.19	23.79	126.94
8	25.01	27.80	26.14	24.30	151.25
9	32.60	34.81	31.11	32.84	184.09
10	42.37	43.94	39.97	42.09	226.18
11	43.97	46.09	46.49	45.52	271.69
12	30.37	30.43	29.97	29.38	301.07
13	28.59	29.88	28.53	29.32	330.39
14	28.29	29.66	27.16	28.43	358.83
15	27.19	28.16	26.67	27.84	386.67
Sum	386.26	388.83	384.86	386.67	

Table 5: Weekly irrigation depth added to the replications by H-SSD

Growing period (Week)	Irrigation depth				Cumulative depth
	$(R_1)^a$	$(R_2)^b$	$(R_3)^c$	Average	Avg.(mm)
1	8.99	7.23	6.94	8.62	8.62
2	9.50	9.55	9.71	10.38	19.00
3	10.55	9.93	10.49	10.46	29.46
4	17.01	10.34	12.08	11.42	40.88
5	17.34	16.48	16.05	17.54	58.42
6	19.77	19.08	19.13	18.30	76.72
7	21.43	21.76	22.81	22.39	99.10
8	22.58	24.79	23.26	23.16	122.26
9	34.50	30.87	35.54	34.67	156.93
10	39.92	47.18	41.79	41.54	198.47
11	51.65	56.75	53.66	54.02	252.49
12	38.85	39.73	38.60	38.67	291.16
13	30.87	30.42	32.81	31.36	322.52
14	29.01	28.55	28.20	29.06	351.58
15	26.23	25.44	27.30	26.62	378.20
Sum	378.20	378.08	378.37	378.20	

Table 6: Weekly irrigation depth added to the replications by C-SSD

Growth, Week	Irrigation depth				Cumulative depth
	$(R_1)^a$	$(R_2)^b$	$(R_3)^c$	Average	Avg.(mm)
1	17.07	16.82	17.04	16.97	16.97
2	25.98	21.09	27.71	25.74	42.71
3	28.41	28.54	30.58	28.68	71.39
4	31.17	34.00	30.75	31.92	103.31
5	32.22	34.41	31.52	32.46	135.77
6	36.72	38.08	34.64	36.48	172.25
7	36.95	38.59	35.28	38.47	210.72
8	37.16	38.96	36.80	38.92	249.64
9	43.90	41.18	39.29	41.61	291.25
10	45.31	43.60	43.24	45.59	336.84
11	48.35	48.45	54.09	46.86	383.70
12	47.60	46.37	48.08	46.68	430.38
13	47.57	44.53	46.51	46.07	476.45
14	44.43	42.56	41.28	43.20	519.64
15	43.04	40.71	39.08	40.24	559.88
Sum	565.89	557.88	555.88	559.88	

What's more, W-SSD and H-SSD treatments showed a great potential to save water ranged from 45% by W-SSD to 46 % by H-SSD as compared to conventional methods (700 mm in average) practiced by the local framers in the area (MOA, 2012). This could be due to the local farmers apply water to the crop regardless of the effective plant needs. These results were similar to findings reported by (Zhang *et al.,* 2004; Enciso et al. 2005 and Davis *et al.,* 2009).

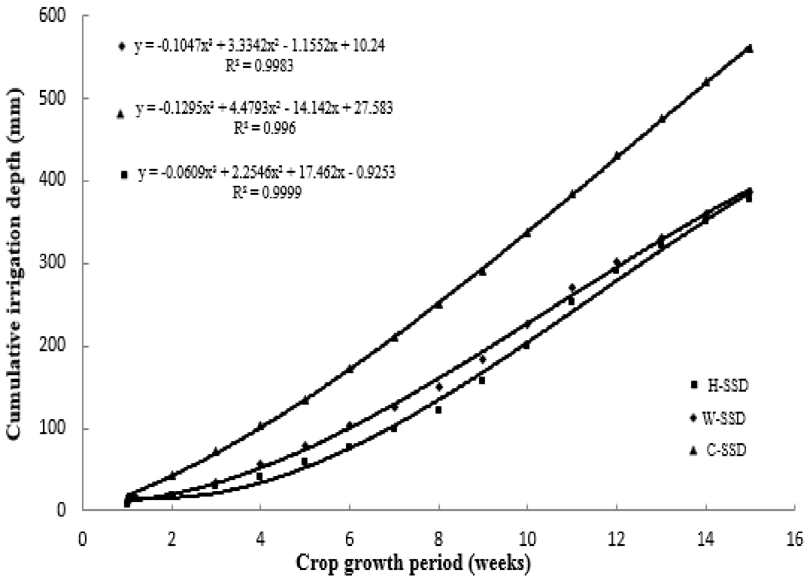

Fig. 2: Comparing WBICs with control concerning cumulative irrigation depth

Agronomical Characteristics

The response of the tomato crop during the growing period demonstrated that variation in applied water by weather- based irrigation controllers (WBICs) and time-based irrigation controller had significant effect on the agronomical characteristics (vegetative growth, fruit quality and fruit yield traits) (tables 7, 8 and 9). The results of analysis confirmed that values of plant height, No of branches, Plant fresh weight (g), Plant dry weight (g), Stem fresh weight (g) and Stem dry weight (g) were significantly increased by 36%, 63%, 67%, 61%, 63% and 66%, respectively under H-SSD compared to the control treatment (table.8). Correspondingly, the increase in vegetative traits under W-SSD were 31%, 45%, 28%, 42%, 44 % and 42 %, respectively. Regarding the fruit quality, the increase in values of fruit length (cm) was by 36%, Fruit diameter (cm) by 38%, Dry matter (%) by 38%, Total soluble solid (TSS %) by 45%, Ascorbic acid by 39% and total acidity (TA %) by 38% under H-SSD treatment as compared to control (table.9). Similarly, the increase in corresponding fruit quality traits under W-SSD treatment was 27%, 29%, 14%, 42%, 34% and 36% respectively as compared to control (C-SSD). The values of total yield (ton/ha), average fruit weight (g) and No. fruit per plant were also significantly increased by 27 % and 11 %; 40 % and 30 %; 18 % and 3 % under H-SSD and W-SSD, respectively as compared to C-SSD (table.10). This could be due to accurately uniform distribution of irrigation water and nutrients under subsurface drip and sensor-based irrigation systems. These results were found to be in agreement with (Jaimez *et al.,* 2000; Fernandez *et al.,* 2005 and Dorji *et al.,* 2005).

Table 7: Vegetative growth characteristics under different treatments

Treatments	Plant height (cm)	No of branches	Plant fresh weight (g)	Plant dry weight (g)	Stem fresh weight (g)	Stem dry weight (g)
W-SSD	69.53b	5.73c	492.47d	93.17c	152.90d	28.97d
H-SSD	74.17a	8.53a	1069.57a	138.47a	230.57b	49.83a
C-SSD	47.76e	3.18d	352.8f	54e	86.22f	16.8e

Values with same letters, within a particular column, are not significantly differ using L.S.D at 0.05 probability level

Table 8: Fruit quality characteristics for tomato plants under different treatments

Treatments	Fruit length (cm)	Fruit diameter (cm)	Dry matter (%)	Total soluble solid (TSS %)	Ascorbic acid (g/100 g FW)	Total acidity (TA %)
W-SSD	5.07c	5.07c	4.39b	6.00b	24.73a	0.58b
H-SSD	5.73a	5.80a	6.07d	6.40d	26.83b	0.59c
C-SSD	3.66e	3.60f	3.78e	3.50e	16.38c	0.37e

Values with same letters, within a particular column, are not significantly differ using L.S.D test at 0.05 probability level

Table 9: Fruit yield components of tomato plants under different treatments

Treatments	Early yield (kg/m^2)	Early yield (ton/ha)	Total yield (kg/m^2)	Total yield (ton/ha)	Average fruit weight (g)	No. fruit per plant
W-SSD	4.4c	44.3c	7.3c	72.58c	125.97c	25.50b
H-SSD	5.41a	54.10a	8.86a	88.56a	147.63a	30.00a
C-SSD	3.96d	39.57d	6.45d	64.53d	88.4e	24.7c

Values with same letters, within a particular column, are not significantly differ using L.S.D at 0.05 probability level

Water Use Efficiency

The crop production and water use data were combined to give water use efficiency (WUE) in yield per volume terms as listed in table 10. The results showed that tomato water use efficiency were in order of H-SSD > W-SSD > C-SSD as compared to control. The maximum value of WUE, 18.88 kg/m3, was determined in H-SSD whereas the minimum value was obtained from C-SSD with 11.52 kg/m3. This results was consistent with (Kirmak *et al.,* 2005 and Sensoy *et al.,* 2007) which considered that the lower amount of irrigation water received the higher water use efficiency achieved. Finally, it could be concluded that irrigation scheduling using new technology contributes to higher water savings, agronomical characteristics and water use efficiency in comparison with the conventional irrigation scheduling methods when it is designed, maintained and used properly.

Table10:Water use efficiency as affected by different irrigation schedules

Treatments	Total yield (kg/m^2)	Irrigation depth (mm)	WUE (Kg/m^3)
W-SSD	7.3	386.67	18.88
H-SSD	8.86	378.2	23.43
C-SSD	6.45	559.88	11.52

CONCLUSION

This study was conducted to investigate the effects of two weather-based irrigation controllers (WBICs) on the water savings and agronomic parameters of tomato crop under subsurface drip irrigation system. Experimental site was located at educational farm of King Saud University on a sandy loam textured soil. Two ET controllers were tested: Weathermatic SL1600; Hunter pro C. The findings indicated that both controllers Weathermatic SL1600 and Hunter pro C applied water less than water scheduled by time clock controller. Where the ET controllers showed the potential to save water ranged from 31% by Weathermatic SL1600 to 32.4 % by Hunter pro C as compared to control treatment. Irrigation savings can be more highly during normal Saudi Arabia rainfall conditions for properly installed and programmed ET controllers. The highest water use efficiency and agronomical characteristics (vegetative growth, fruit quality and fruit yield traits) were found in Hunter pro C and Weathermatic SL1600 treatments, respectively and the lowest one was found in control treatment.

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الري الذكي في محاصيل الخضر (الطماطم): نهج مبتكر لاستخدام موارد المياه

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تم استخدام وحدتين مختلفتين من أجهزة التحكم الذكية في هذه الدراسة، هما هانتر برو سي و ويزر ماتك سمارت لاين ١٦٠٠ وكلاهما متاح في السوق المحلي، وكلاهما من نوعي الأجهزة التي تعتمد في عملها على البخر نتح في ري المحصول. حيث يتم تنفيذ برنامج جدولة الري تلقائيا، استنادا إلى الظروف المناخية المحلية المستنبطة من مكونات أجهزة الري الذكي المتمثلة في: (أ). مجسات بخر نتح؛ (ب). وحدات نمطية و (ج). أجهزة تحكم. الميزة الرئيسية للسيطرة على الري بواسطة هذه التقنيات هي أن النظام يقوم بضبط أوقات تشغيل الري تلقائيا بناء على بيانات الموقع (مثل رطوبة التربة، المطر، الرياح، الانحدار، التربة ونوع النبات..الخ)، ومن ثم تطبيق الكمية المناسبة من المياه على أساس تلك العوامل.

وقد تم دراسة تأثير هذه التقنيات على إنتاجية محصول الطماطم وكفاءة استخدام المياه تحت نظام الري بالتنقيط تحت السطحي خلال الموسم الشتوي ٢٠١٣-٢٠١٤ في تربة رملية طميية تقع ضمن نطاق جامعة الملك سعود، الرياض، المملكة العربية السعودية. وقد أشارت النتائج إلى أن أجهزة التحكم الذكية يمكنها التوفير في استهلاك مياه الري بنسبة ٣٢.٤٪ و٣١٪ لكل من هانتر برو سي و ويزر ماتك سمارت لاين ١٦٠٠، على التوالي دون أن يؤثر ذلك سلبا على انتاجية المحصول مقارنة بجدولة الري التقليدية (الكنترول). وعلاوة على ذلك، فان كلا من كفاءة استخدام المياه، الاوزان النباتية، ارتفاع النباتات، والمؤشرات الفسيولوجية الأخرى أكدت أولوية أجهزة الري الذكي.