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The performance of irrigation automation system based on soil moisture level for pepper (*Capsicum annuum* L.) growth

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Abstract

Automated control systems in irrigation have in recent years made considerable progress, offering a wide range of new options. In this experiment, a closed loop control system based on the relationship of electrical resistance and soil moisture was used to test the performence of the automated drip irrigation system for pepper (*Capsicum annuum* L.) growth. A main strategy for irrigation was determined before irrigation events and the pot (100kΩ) in the circuit was adjusted to the strategy determined before, thereafter a signal was produced by the electrodes embedded in the substrate whenever soil moisture reached to the threshold level. Therefore, the system took over irrigation events, started and stopped the irrigations throughout the entire growing season. The irrigation times and amounts of irrigation water applied by the system was not suitable for uniform crop production, because irrigation throuhout the whole growing season was commenced as almost 55% of the available soil moisture was depleted from field capacity (FC).

Key words:Irrigation, automation, pepper, sensors.

Introduction

Control systems for water supply installations have in recent years made considerable progress, offering a wide range of new options. The irrigation systems, sprinkler, furrow, and drip used for sugar beet were converted into automated controller systems in Switzerland [15], in which the whole area (4000 ha) was divided into small irrigation units (100 ha) and a controller unit was established into each small segment. By this way, automation between these units were provided by radio waves and all segments are irrigated in sequence to match the flow of water available from the resource of water. Scientists [19] used gypsum resistance block as a soil moisture sensor to activate automatically sprinkler irrigation system. Draper [6] developed an irrigation scheduling computer program, using the relationship between soil texture, soil water holding capacity and the soil matrix potential. Cuming [5] controlled the common lines of various irrigation systems by using a soil moisture sensor. Phene [16] used automated evaporation pan systems to schedule irrigation for trees. Quesenberry *et al.* [20] used the climatologic data taken from weather stations for irrigation scheduling.

Another approach of irrigation scheduling is by determining the water stress in plants as plant development is closely related to the water balance in plant tissue. Therefore, it is possible to determine water stress in plants by using a hand held infrared thermometer. This technique is very useful for detecting disease and insect damage assessment, also for irrigation scheduling and yield prediction of water-deficit-stressed crops [8] and to assess rapidly water stress in plant canopies at both leaf and canopy scales [4]. The water content in plant tissues represents the relationship between the soil water potential, rooting density and distribution as well as other plant characteristics [14]. The Crop Water Stress Index (CWSI) has been shown to be closely related both to extractable water in the root zone of a wheat crop [18] and to the plant water potential in wheat and alfalfa [10]. Jackson *et al.* [13] reported that water stress causes plants to close their stomata according to the degree of water stress, reducing transpiration.

There exist many ways to start irrigation automaticaly such as time based, volume based, real time feedback system [12]. In this experiment, the closed loop system running to reel time feedback system, designed by Abraham *et al.* [1], was used. Therefore, the objective of this article is to show how well the automated irrigation controller senses soil moisture level and maintaines the desired soil moisture levels for pepper (*Capsicum annuum* L.) growth.

Materials and Methods

The experiment was conducted from May to the end of August 2008 in outdoor conditions and near the Straits of Canakkale (Dardanelles) in Turkey. The geographical location of the experimental area was 40°6’32.64’’ N latitude, 26°24’45.31’’E longitude and 5 m elevation. Nurseries planted with peppers (*Capsicum annuum* L.) were transplanted into containers on May 23, 2008. The containers were in the form of 150 cm in length, 16 cm in width and 12 cm in depth, resulting in a 0.24 m^2 surface area and a volume of 28.8 L and included 5 plants each. There was a drainage hole at the end of each container. The substrate was a mixture of torf (4:1, v/v) and soil (4:3, v/v) which consisted of sand (58%), silt (23%) and clay (19%). Temperature (°C) and relative humidity (%) at the site were measured 1.5 m above the canopy of the plants by using a HOBO U12 instrument (Fig. 1), and measurement range is from -20°C to 70°C for temperature, 5% to 95% for humidity. Some physical and chemical characteristics of the substrate and quality of the irrigation water are given in Tables 1 and 2, respectively.

Each container in the experiment took the same amount of fertilizers, triplesuper phosphate (3 g $plant^{-1}$), potassium sulfate (3 g $plant^{-1}$), and urea (3 g $plant^{-1}$). Urea was applied to each container two times more at 15 and 20 day intervals, respectively, after planting at the same dosage. The irrigation system in each treatment included the following components; the water storage tank (50 L), submersible pump operating at 12V dc and 2.05 A, power supply (12 V dc), containers (150 x 16 x 12) cm, Ø16 pipes with drippers (4 L/h) at a spacing of 33 cm, with one dripper serving each plant. Valves and connection apparatus were used to integrate all items of the irrigation system. The layout of the experiment is given in Fig. 2.

The most important components of the automated system were the sensor and electronic circuit. The sensors and electronic circuit were given in Figs 3 and 4, respectively. Sensors made of brass with size of 3 cm x 3 cm were placed at a depth of 5 cm from the surface. The threshold value for irrigation to be started was determined as 30% of available soil moisture (weight mass, g/g) in the root zone was depleted by a representative plant. The electrical resistance corresponding to that moisture content level was found to be 18 kΩ for the sensors (Fig. 5). The resistance value was set to the pot (100 kΩ) in the circuit (Fig. 4). A signal was produced by the electrodes embedded in the container whenever soil moisture was consumed to a certain level, which resulted in a high voltage at the base pin of BC547, that is, as the voltage rose at the base pin of BC547, the high voltage triggered the relay and then water was conveyed to the plant root zone by dripper lines.

All pots were weighed daily to determine daily evapotranspiration (ET). To achieve this, the water balance method was used between the two irrigations [21].

$$ET = [((W_{i-1} - W_i) + I - D)/A] \qquad i = 1,2,3,\ldots\ldots\ldots n \qquad (1)$$

where ET is the evapotranspiration (mm), W_{i-1} and W_i mass (kg)

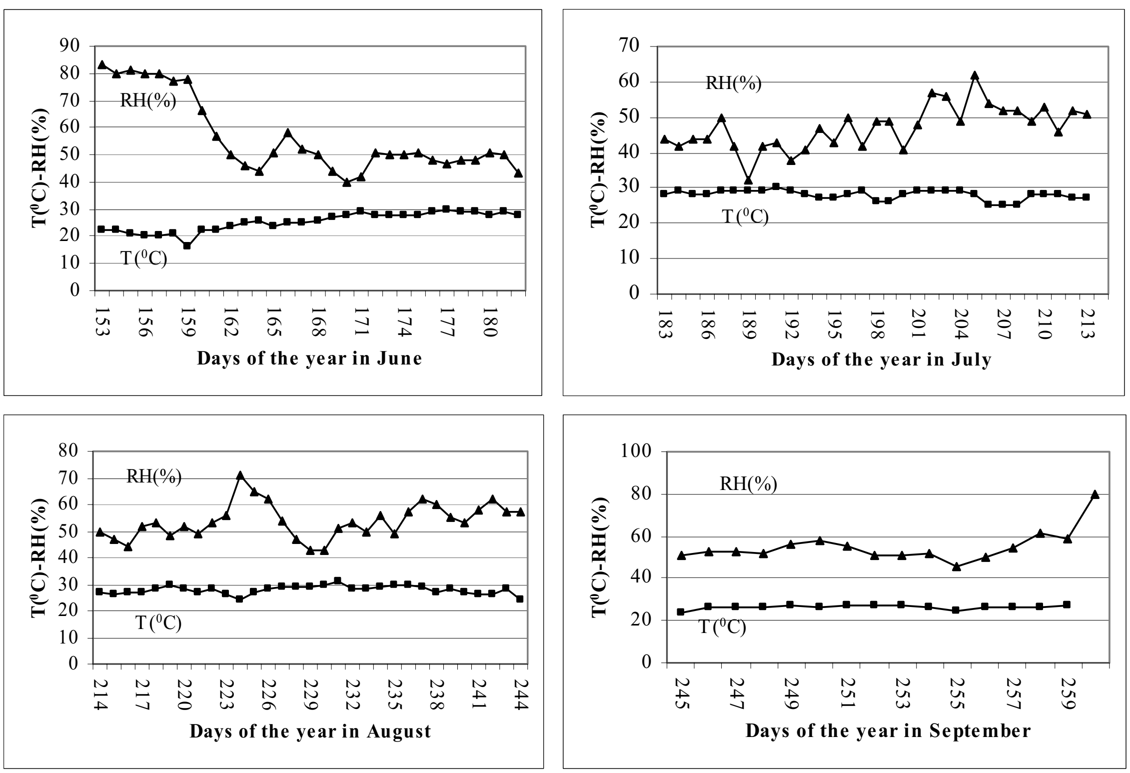

Figure 1. Meteorological data for period of experiment.

Table 1. Chemical characters of substrate used in experiment.

pH	EC ($dS\ m^{-1}$)	Field Capacity (%)	Wilting Point (%)	P (kg/ha)	K (kg/ha)	Ca (ppm)	Mg (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	$CaCO_3$ (%)
6.0	1.37	46	11	22.6	6138	8111	2500	3.12	5.20	5.00	13.80	5.23

Table 2. Quality of irrigation water used in experiment.

pH	Na %	EC $dS\ m^{-1}$	SAR $(mel^{-1})^{1/2}$	RSC	Cation me l^{-1}					Anion me l^{-1}				
					Na	K	Ca	Mg	Total	HCO_3	CO_3	Cl	SO_4	Total
7.32	0.14	0.98	0. 67	None	1.37	0. 17	3. 7	4.6	9. 84	3.8	-	2.8	3.24	9.84

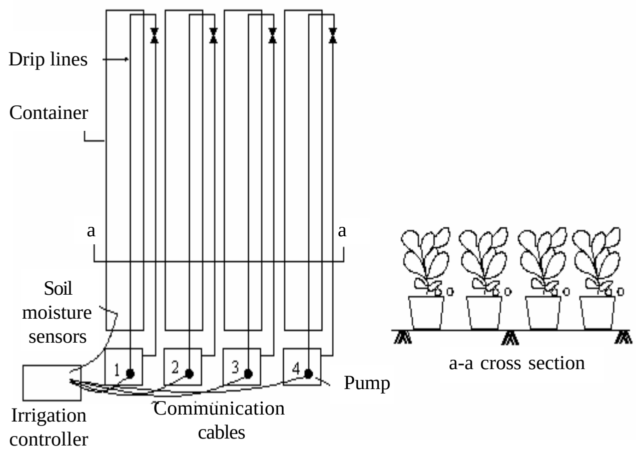

Figure 2. Layout of the experimental components.

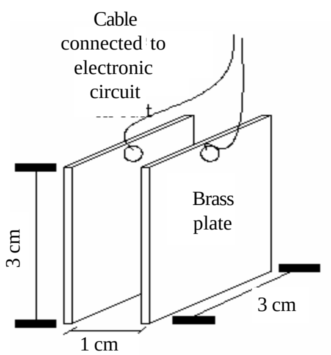

Figure 3. View of the soil moisture sensor, made of brass.

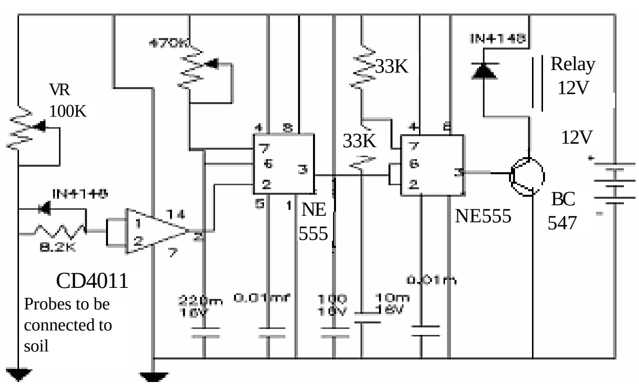

Figure 4. Circuit of irrigation controller [1].

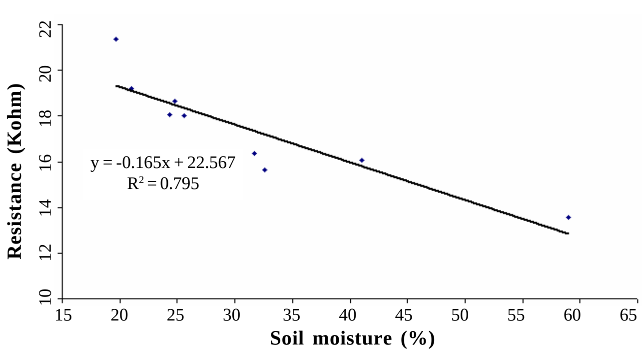

Figure 5. Electrical resistance differential depending on soil moisture level.

of the pot at day (i-1)th and (i)th, respectively. I is the amount of irrigation water (kg), D is the quantity of the drainage water if available (kg), and A is the pot surface area (m²). Water use efficiency (WUE) (kg mm^{-1} plant^{-1}) and irrigation water use efficiency (IWUE) (kg mm^{-1} plant^{-1}) [9] were estimated as:

$$WUE = Y / ET \qquad (2)$$

$$IWUE = Y / I \qquad (3)$$

where Y is yield (g), and I is irrigation depth (mm).

Canopy temperature (Tc) was measured with a (Tesco, model number is 810) hand held infrared thermometer (IRT) with a resolution of 0.1°C and optics of 6:1. Emissivity was set to 0.98. Canopy temperature data collection began when nurseries reached an average of approximately 17 cm tall on the 168th growing day of the year. The IRT readings were taken from two cardinal compass directions. The instrument was held about 1.5 m above ground level and directed to a single leaf of the crop with the help of the laser point of the instrument at about a 30° angle to the horizontal. The two readings were averaged per crop. The principal observation period of all plants was from 12.00 to 14.00 h at near solar noon. When the readings from IRT were performed, wind speed was either 2 m s^{-1} or less and the sky was clear. Vapor pressure deficit (VPD) was determined from wet and dry bulb readings by using a psychrometer [2]. Mean atmospheric pressure of 101.3 kPa was used to calculate VPD for the coastal area of Canakkale. The values of the crop water stress index (CWSI) were calculated based on the empirical equation [10]:

$$CWSI = \frac{[(T_c - T_a) - (T_C - T_a)_L]}{[(T_C - T_a)_U - (T_C - T_a)_L]} \qquad (4)$$

where T_c is canopy temperature (°C), T_a is air temperature (°C), $(T_c\text{-}T_a)_L$ is the lower limit and $(T_c\text{-}T_a)_u$ is the upper limit for pepper (*Capsicum annuum* L.) growing in the coastal area of Canakkale, obtained from the measurements of fully transpiring and none transpiring crops, respectively. The values of CWSI in other treatments were scattered between these two baselines.

All plant weights (stem and leaf) were determined using a sensitive weighing (0.01 g) and diameters were measured with a digital clipper (to 0.01 mm). Leaf area was determined by CI-202 area meter (CID, inc.) as cm², all leaves of each plant were collected in all treatments, and leaf area index (LAI) was measured as the ratio of total leaf area of a plant to the container area. Soluble solids were determined on a blended composite using Serico portable hand refrectometer. Titratable acidity was determined for the composite consisting of 10 ml fruit juice and 20 ml distilled water by titrating to an end point of pH 8.1 with 0.1N NaOH by a pH meter (Milwaukee Comp.). Ten nurseries at planting were randomly chosen and the parameters such as leaf number, stem diameter, LAI, etc. were measured and averaged, then the same values were assigned to each treatment for May 23, 2008 at the beginning of the experiment.

Results and Discussion

The response of the soil moisture sensors in resistance to the variation of soil moisture level is given in Fig. 5. The figure shows that resistance between two electrodes declined as the level of soil moisture increased. The strategy for irrigation was to commence whenever moisture content decreased 30% below FC, therefore, the resistance value corresponding to the threshold level of soil moisture in the substrate was obtained as 18 kΩ in Fig. 5, which was defined to the pot (100 kΩ) in the circuit. Water according to the pre-set strategy was applied by the automated system whenever soil moisture was depleted out of the root zone up to the critical level, even application of water more than the upper level took place on 191th, 193th, 196th, 200th days during the experiment.

Fig. 6 indicates the graphical display of the action rootzone depletion and the timing of the irrigation events throughout the calendar days. The automated system at 147th calendar day run pump till increasing soil moisture level from 10% to 47% by applying water of 22.3 L. In the second irrigation event, on 157th day, the system started irrigation and elevated soil moisture level from 23.3% to 32.2% by that of 4.3 L, but one day later, on 158nd day, the system triggered pump again and soil moisture reached 41.5% by that of 4.85 L. Irrigation interval was in average 8 days till 165th day, after that day the average irrigation interval declined to 3 days throughout the days between 165th and 241th calendar year. On 184nd day, as soil moisture dropped the lowest level of 10% in the substrate and also the system applied the highest amount of irrigation water of 19 L. Eventhough the level of field capacity was maintained nearly constant as 47% by the irrigation controller, the system did not keep the threshold level of soil moisture which was defined as a pre-strategy by adjusting the resistance value of 18 kΩ to the pot (100 kΩ) in the circuit. Abraham *et al.* [1] reported that some ion deposition reduced the electrical conductivity between two electrodes, because of that reason, in this experiment such deposition of ions between two plates delayed the start time of irrigation since the electrical conductivity of irrigation water used was 1 dS/m and no leaching water existed from the substrate, since the system did not apply exess water during the experiment.

Plant temperature is an important tool in quantifying plant stress between irrigations and monitoring yield potential [17]. In this experiment, the lower baseline for fully transpiring pepper was described after the measurement of canopy and air temperature as T_c-T_a = 2.5102-0.2834 VPD with r^2 of 0.92, where T_c-T_a is in °C and VPD in kPa. The upper limit representing T_c-T_a for plants under severe stress was relatively constant at about +5.0719°C. The fluctuations of the CWSI values, irrigation dates and amounts for all irrigation treatments throughout the entire growing season were compiled and are shown in Fig. 7. On 185th day, the highest CWSI occured since no irrigation water was applied after the day of 177th. It, however, immediately started dropping after water application of 23.71 L and 8.1 L on 184nd and 186nd days. Then, the values of CWSI were considerably stable around 0.05 throughout the whole growing season. Leaf-air temperature differential has a direct relationship with soil moisture content [1]. CWSI is a relative measure of the plants' ability to meet evaporative demand and offers several important advantages over conventional approaches for quantifying plant stress between irrigations and monitoring yield potential [17].

In the experiment, the applied water, evapotranspiration, WUE and IWUE were 218.1 mm, 344.8 mm, 61.5 kg mm^{-1} da^{-1}, 97.2 kg mm^{-1} da^{-1}, respectively. The evapotranspiration demand of

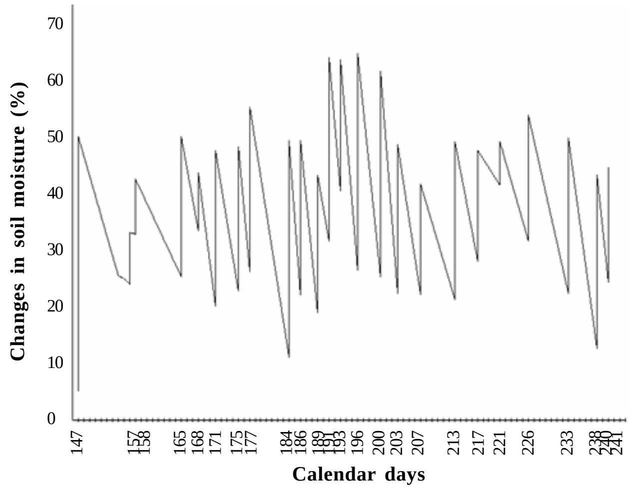

Figure 6. The graphical display of action rootzone depletion and water applied.

peppers for the entire growing season were not compansated by the automated system. Moreover, yield and quality parameters were low due to low amount of irrigation water applied (Tables 3 and 4). The main reason of low yield and quality parameters of pepper was ions deposition between two electrodes which did not permit the resistance increase to start irrigation at the time that 30% of soil moisture was depleted from FC. The rate of water application by the system was less as compared with research, Gadissa and Chemeda [7] applied 180.4, 272.4, 360.2 mm irrigation water and obtained the yield of 8.57, 12.8, 16.57 t ha^{-1}, respectively. Imtiyaz *et al.* [11] reported that evapotranspiration of tabasco pepper (*Capsicum annuum* L.) for the whole growing season is 888 mm. Atak [3] suggested that pepper (*Capsicum annuum* L.) should be irrigated with 4 days intervals and seasonal irrigation water and evapotranspiration for pepper were 359.5 mm and 405.5 mm, respectively. Therefore, in this experiment due to low water application by the system plants remained small and compact. Plant development parameters in terms of plant height, stem diameter, LAI were inhibited, the effect of those caused yield to be less too.

Conclusions

The prototype of the automated irrigation system designed by Abraham *et al.* [1] was tested to determine its performance for the irrigation of pepper (*Capsicum annuum* L.). Controler performance was evaluated by determining soil moisture with two electrodes. The system failed to determine the level of the irrigation to be started at, especially on 184nd day, the soil moisture level was the lowest level with 10.9%, which caused plants to be under stress. Therefore, CWSI at this time was developed and reached to the highest stress level througout the whole growing season. Eventhough, the irrigation interval was reasonable for pepper growth, a soil moisture sensed by the automated irrigation controller has not been satisfactorily estimated, especially the below threshold level to start irrigation, almost for all growing season irrigation was initiated as 55% of soil moisture was depleted from FC. Another most important point is the installation of the sensors into the substrate, because it may change the trigger time for an irrigation event, and also the system immediately stopped irrigation as soon as water contacted with sensors. Therefore, it is better to use microprocessor in the automated systems, they provide much more control flexibility, also they have very low cost, they can be used in the circuits as a controller.

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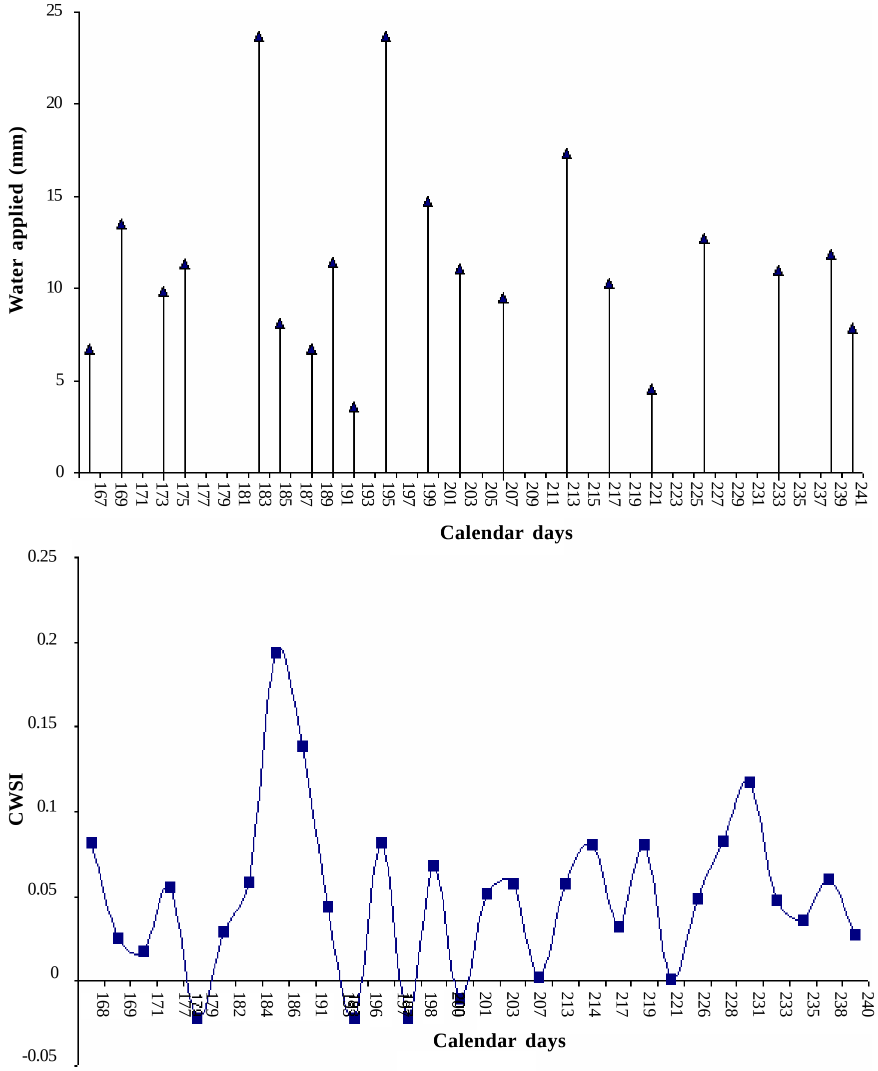

Figure 7. Changes in CWSI due to irrigation applications throughout the growing season.

Table 3. Effects of automated irrigation application on plant development.

Parameters	Planting date (23 May)	Harvesting date (28 August)
Whole plant weight (g)	2.67	32.70
Stem weight (g)	0.65	12.72
Leaves weight (g)	1.42	13.37
Root weight (g)	0.53	5.02
Plant height (cm)	11.3	36
Stem diameter (mm)	2.31	4.40
Leaf area (cm^2)	41	494.61
Leaf number	12	42
LAI	0.12	1.43

Table 4. Effects of automated irrigation application on yield and fruit quality.

Sampling dates	Yield (g)	Mean fruit weight(g)	Fruit length (cm)	Soluble solids(%)	pH	Titratable acidity (%)
10 July (DOY 192)	190.5	11.1	10.5			
25 July (DOY 207)	252.1	8.2	8.32	6.4	6.06	0.057
15 August (DOY 228)	190.1	6.2	8.62			
28 August (DOY 241)	183.6	4.7	8.20	5.5	5.98	0.021