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EVALUATION OF AN ELECTRONIC IRRIGATION SYSTEM WITH INTERNET CONNECTION IN STRAWBERRY CULTIVATION

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Abstract

Efficient usage of water resources is critical for several problems related with environment. Therefore, the irrigation systems enabling precise application of water are important for environmental protection. Besides, determining water need of plants correctly and applying the relevant amount of irrigation water precisely are important issues in water management due to their relations with sustainability of the sources, crop yield maximization and water-related diseases. In this work, an automated electronic irrigation system addressing these issues was developed and tested on strawberry cultivation under the Spanish-type high tunnel. The water level in an evaporation pan was measured through a sensor to calculate the irrigation amount. Rubygem and Fortuna varieties were cultivated under four irrigation regimes (IR125, IR100, IR75, IR50). To evaluate the morpho-physiological responses to irrigation levels; leaf area, crown number, leaf number, plant width, midday leaf water potential, net photosynthesis, and stomatal conductance (Sc) were measured. The Fortuna cultivar had significantly higher Sc, causing 14% higher photosynthesis than Rubygem. Hence, the Fortuna yield was approximately greater 100 g/plant than Rubygem. The maximum yield was 1046.1 g/plant for IR100 which was reduced up to 435.8 g/plant for IR50. It is concluded that this situation is directly related with lower values for Sc, leaf water potential and photosynthesis. As a result, the amount of irrigation water was found pivotal to reach desired yield and fruit quality in strawberry cultivation.

Key words: fruit quality, pan evaporation, plant physiology, stress condition, yield

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1. Introduction

As a consequence of the ever-increasing human population, the natural resources are diminishing rapidly and in turn serious changes in climate are being observed. In this respect, various methods for the efficient use of the natural resources are being developed and utilized all over the world. One of the mostly consumed and wasted resource is water. This crucial resource for life, is being used in countless areas including energy production, healthcare and agriculture.

The efficient use of water resources in agriculture is very important not only for the conservation of the sources but also for maximizing the crop yield and reducing the occurrence probability of water-related diseases. Thus, it is necessary to utilize the technological advancements and data processing methods in modern agricultural systems in order to optimize the amount of irrigation water.

Strawberry production plays an important role in the agricultural sector of the Mediterranean part of Turkey, because the employment and income rates it provides are very high. For increasing the strawberry yield, effective cultivation practices and optimization of applied irrigation water are very critical. Even though there is a widespread usage of different irrigation regimes in strawberries, the specific water

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requirements for strawberry are uncertain (Lozano et al., 2016). There are numerous irrigation water applications mentioned in the existing studies, yet they contain differences like climate, method of production, cultivar, and calculations for water requirement (Hancock, 2020; Lozano et al., 2016). The calculated irrigation requirement for strawberry in Huelva, Spain was in between 564 and 795 mm per year and the corresponding fruit yield was in the range 1,027 and 1,084 g/plant (Lozano et al., 2016). In addition, for the central coast of California, irrigation water and yields varied in the ranges 300-700 mm/yr and 20-50 $t \cdot ha^{-1}$, respectively (McNiesh et al., 1985). In the Mediterranean region of Turkey, the optimal water application on strawberries was approximately 400 mm (Sarıdaş et al., 2021). At local trials, applying varying irrigation amounts allows for enhancement of irrigation management in dedicated regions and agricultural systems. Application of irrigation water in non-optimal amounts brings about the plant stress and eventually cause decrements in fruit yield and quality on strawberry. Therefore, scheduling of water application is very important for optimal usage of irrigation water through drip irrigation in the modern agricultural practices such as the computer-based automated irrigation systems.

The computer-based automated irrigation systems commonly utilize soil moisture sensors to make a calculation concerning the total amount of irrigation. The earlier studies in this context aim at automatically keeping the soil moisture level at a user-defined threshold (Nemali and Iersel, 2006). On the other hand, recent studies involve more complex features like data analysis methods, internet connection, wireless data transmission, and solar energy. For instance, the automated irrigation system was developed such that the irrigation is initialized when the soil moisture in a cucumber field becomes smaller than a threshold value (Touati et al., 2013). Through the sensors in the system, various data such as soil moisture, ambient temperature, solar radiation and the amount of water consumed were measured. These data were fed to a fuzzy logic controller to control the irrigation. The system also featured Zig-Bee and GPRS modules to handle wide range data transmission and internet connection. In another study, microcontrollers and wireless communication devices were utilized in addition to soil moisture and temperature sensors (Gutiérrez et al., 2014). The system was also connected to the internet and the relevant data was continuously sent to a web application and the actuators were controlled. The water quantity related to irrigation was determined by predefined threshold values for soil moisture and temperature.

One of the alternative ways of determining irrigation water requirement, and hence the irrigation amount, is the use of evaporation pans. A pan supplies a measurement of the combined effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop evapotranspiration which means crop water requirement (Allen et al., 1998). Researches have reflected that evaporation pans can be used in the irrigation programs and correlation between pan evaporation and crop evapotranspiration is higher than other empirical relationships (Ertek, 2011). The water level decrement inside the pan is observed on a regular basis and the total water requirement of the plants is estimated through that observation. The studies utilizing evaporation pans are focused on investigating the effects of different watering regimes on the number and quality of the yields (Kumar and Dey, 2011, 2012; Li et al., 2012; Wang et al., 2009; Yuan et al., 2004; Zeng et al., 2009). In such systems, observation of the water level in the pan and the control of the valves are performed manually. Obviously, such an application is prone to human-related mistakes and also causes loss of time and energy.

Since the usage of internet and smartphones have become very widespread in the last decade, the contemporary irrigation systems may typically involve a web interface (González et al., 2017) or a smartphone application (Bartlett et al., 2015; González et al., 2017; Saab et al., 2019). Utilization of such smartphone applications have been reported to be useful in effective use of water resources by means of mobilizing the user interaction. Hence, the critical information like level of soil moisture and weather forecast become available to the farmer in an expedited way (Bartlett et al., 2015). In addition, cloud-based data processing studies contribute to improvement of irrigation practices. For example, thermal imaging makes it possible to collect important information for a smart irrigation system in which the areas requiring more water are determined by processing these images at the cloud servers (Roopaei et al., 2017). However, transmission of the detailed data to the cloud may bring about some problems such as increased network traffic and vulnerabilities in network security. One solution to these problems is to implement an edge computing network where only a reduced amount of data is transmitted to the cloud. An example edge computing architecture for strawberry irrigation in greenhouse environments was proposed recently (Angelopoulos et al., 2020). In that work, soil moisture was measured as the only parameter to initialize and stop the irrigation process. It was experimentally shown that the developed smart irrigation system contributes to water saving by optimal irrigation.

Despite the recent increments in the number of automated and smart system applications in agriculture, to the authors' knowledge, automated irrigation systems involving evaporation pans together with internet connectivity and a smart phone application has not been mentioned yet. On the other hand, some computer based automated irrigation systems utilize processing of various sensor data such as soil moisture, temperature, solar radiation, relative humidity, and wind speed. Irrigation scheduling tools with automated irrigation capabilities has been developed by processing these data. However, the total amount of water savings is reported as the performance metric in majority of such works (González et al., 2017; Gutiérrez et al., 2014; Migliaccio et al., 2015; Nawandar and Satpute, 2019; Poyen et al., 2021). Besides, the provided yield-related results are very limited in the other studies (Muangprathub et al., 2019; Saab et al., 2019).

In this experimental work, an automated drip irrigation system involving an internet connection and a smart phone application is developed. Overall system features were presented in one of our earlier works (Avşar et al., 2018), now the performance of the system has been reported with detailed experimental results. Parameters related to yield, green parts characteristics, plant physiology, and fruit quality have been collected for two different strawberry varieties (Rubygem and Fortuna) and compared for the four different irrigation regimes. As for the regression analysis, three performance metrics namely, R^2, root mean squared error (*RMSE*), and mean absolute percentage error (*MAPE*) were calculated.

2. Materials and methods

2.1. The irrigation system

The aim of this irrigation system is to automatize the irrigation procedure. In the conventional manual procedure, a person checks the water level inside the Class A pan regularly, calculates the required irrigation duration according to the decrement amount obtained from the last measurement, and keeps the valves open for that duration. However, the developed system of this study determines the water level with a sensor and calculates the relevant irrigation duration automatically. Consequently, valves are opened upon the approval of the user and closed automatically when the time is up.

The system consists of four major units: *(i)* Power and actuator unit, *(ii)* Data collection unit, *(iii)* Control and network unit, *(iv)* Monitoring unit. The overall diagram of the system is given in Fig. 1. Power and actuator unit consists of a transformer and four solenoid valves. The valves are controlled by the signals coming from the *Control and Network Unit* that involves a GSM/GPRS module to establish the internet connection. Whenever the input of the connected relay is triggered, the valves are energized and hence the irrigation is initialized.

The water level sensor, environmental sensor and a wireless transmitter constitute the data collection unit. These components were placed next to the evaporation pan in order to allow the convenient connection between the water level sensor and the control circuit (Fig. 2). The web service used in this work is ThingSpeak (https://thingspeak.com/). It is a cloud-based web server for internet of things (IoT) applications to store, visualize and analyze data. Only the data storage feature of this service is utilized in this work. The new measurements are sent to the web server in every 60 seconds. Since the data collected within the system does not change rapidly, this is a reasonable length of interval for the system.

The monitoring unit of the system is an Android application that can be used in smart phones and tablets. All of the relevant conditions in the greenhouse are accessible to user through this application (Fig. 3).

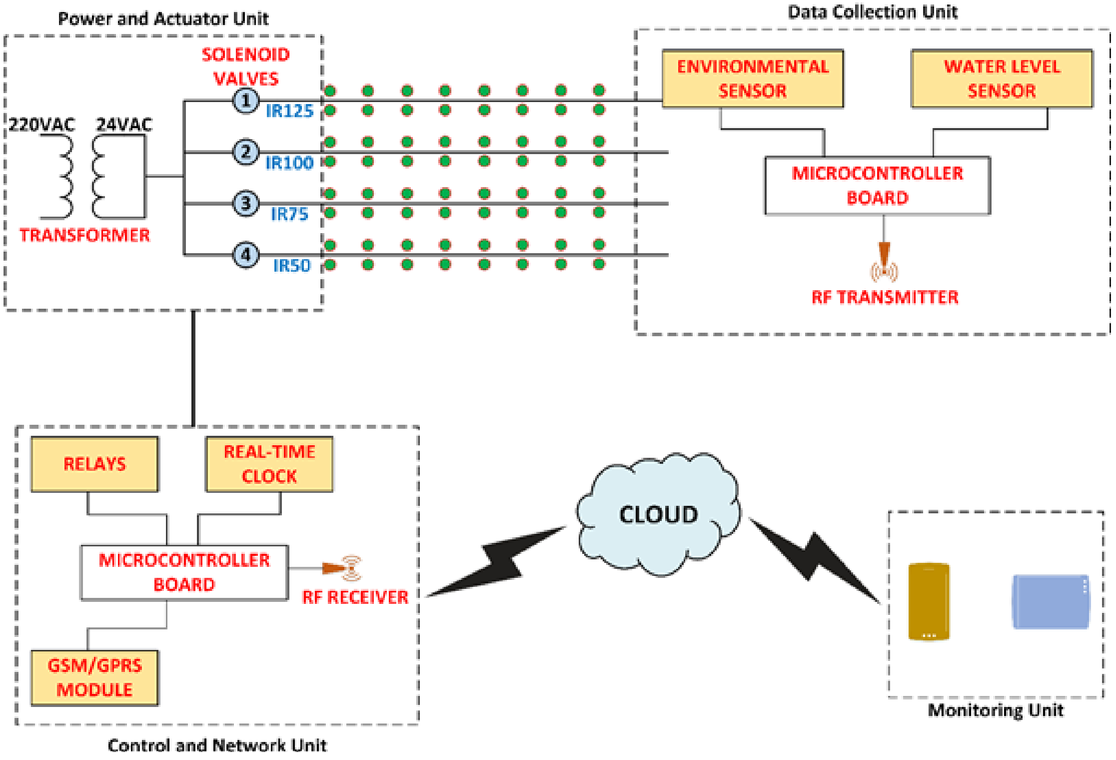


Fig. 1. The overall system diagrams

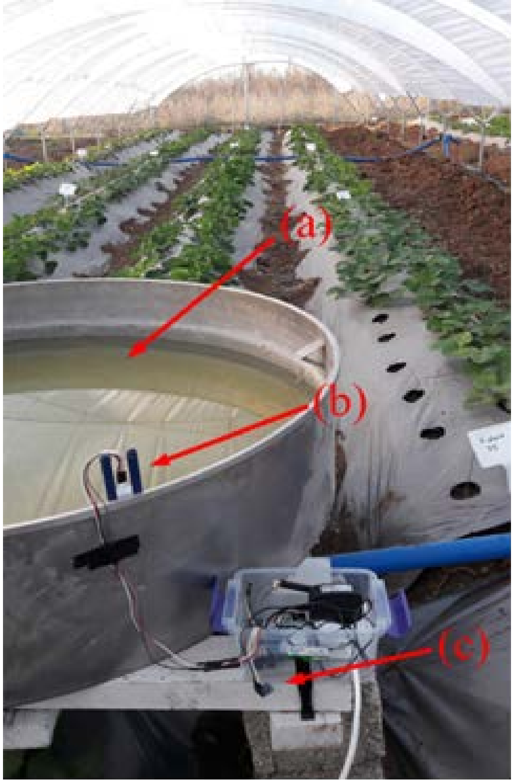
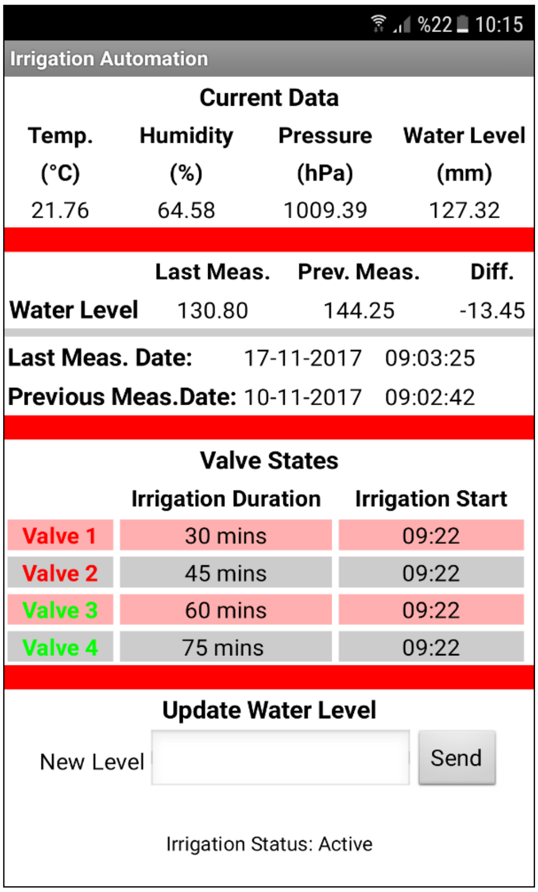


Fig. 2. The data collection unit inside the greenhouse. (a) evaporation pan, (b) water level sensor, and (c) environmental sensor



Irrigation Automation

Current Data

Temp. (°C)	Humidity (%)	Pressure (hPa)	Water Level (mm)
21.76	64.58	1009.39	127.32

	Last Meas.	Prev. Meas.	Diff.
Water Level	130.80	144.25	-13.45

Last Meas. Date: 17-11-2017 09:03:25
Previous Meas.Date: 10-11-2017 09:02:42

Valve States

	Irrigation Duration	Irrigation Start
Valve 1	30 mins	09:22
Valve 2	45 mins	09:22
Valve 3	60 mins	09:22
Valve 4	75 mins	09:22

Update Water Level

New Level

Irrigation Status: Active

Fig. 3. The monitoring unit

2.2. The experiments

The experiments were executed inside the high tunnel at the Çukurova University experimental farm. The strawberry (*Fragaria-ananassa* Duch. cvs.) Rubygem and Fortuna, of short day type, earliness, good taste and aroma, were planted on September 22, 2017 and cropping continued until June 11, 2018. The frigo plant material was used.

Trapezoidal raised beds were used for planting the strawberries. The dimensions of the beds were 0.70, 0.50, 0.30 m for the base, top, and height, respectively. The distance between each bed was adjusted to be 0.30 m. The beds were covered with a two-sided polyethylene mulch cover with a thickness value of 0.05 mm. The mulch cover had grey color on the upper side and the other side was black. Following the agricultural conventions in the Mediterranian region, surface drip irrigation was installed on the top center of the beds under the mulch covers. Two rows of strawberries were planted on each bed with plant set 30 cm apart. The corresponding plant density for this planting scheme is 6.65 plants/m^2. During the initial stages after planting, adequate amount of water used for irrigation to ensure that all plants are well developed. To control diseases, uniform amount of fertilizer was applied through drip irrigation as well as foliar application in each treatment.

The drip tube with a diameter of 16 mm was fed with fresh water with a salinity value of 0.18 d/m. The four different irrigation treatments were realized by four 10 m by 4 m plots equipped with these drip tubes in which the distance between the emitters is 30 cm, the water flow rate is 2.7 L/h, the distribution uniformity is 95%. Mature strawberry fruits were harvested twice a week from The amount of irrigation water was calculated by using Eq. (1).

$$t = (A \times E_p \times p_c \times k_{cp})/(q \times n) \tag{1}$$

where: t is the irrigation time (hour); A is the area of the plot (m^2); E_p is the cumulative free surface water evaporation at irrigation interval (mm); p_c is the plant cover (initial: 35%, end: 70%); k_{cp} is the crop-pan coefficients of 0.5 (IR50), 0.75 (IR75), 1.00 (IR100), 1.25 (IR125) for various irrigation regimes throughout the trial; q is the flow rate of emitters; n is the number of emitters in the plot.

The effect of the different irrigation regimes on the harvest can be seen clearly from the results. Throughout the experiments, the total water applied to treatments IR125, IR100, IR75 and IR50 were 552, 447, 342 and 237 mm, respectively. In order to evaluate the morpho-physiological responses of strawberry, the leaf area, crown number, leaf number, plant width, midday leaf water potential (Ψ_b, bar), net photosynthesis (μmol CO$_2$ m^{-2} s^{-1}), and stomatal conductance (gs, μmol m^{-2} s^{-1}) were measured.

The midday leaf water potential was measured via a pressure chamber (Soil Moisture Equipment Corp., Santa Barbara, CA, USA) and the net photosynthesis and stomatal conductance (*gs*) were measured with a Model CI-340 Handheld Photosynthesis System (CID Devices). Measurements were taken on fully expanded upper canopy leaves (three leaves per plot) from 11:00 to 13:00 hours. Three plants from each plot were cut at the soil surface, their leaflets separated from the petioles, and LA measured with a leaf area meter (model 3050A; Li-Cor Lincoln, NE, USA). The same plants were used to determine the crown number.

Harvesting was performed twice a week between February and June. The average fruit yield (g/plant) was determined by total weight of fruits from ten selected plants from each treatment where the fruits were weighed on the harvest date.

The data obtained were analyzed with the statistical program JMP version 5.0.1 (SAS Institute Inc., Cary, NC). ANOVA was carried out to determine the differences between the cultivars, irrigation regimes and active harvest times in terms of examined parameters. To analyze the differences between the groups, least significant difference test was performed. The threshold value for statistically significance was set to be P≤0.05 for the comparisons.

2.3. Regression analysis

In addition to plant-related measurements from different irrigation regimes and varieties, the relation between the daily water level decrement from the pan and the environmental data (temperature, relative humidity and pressure) was also investigated. This is accomplished by generating regression models on the environmental data to predict the amount of evaporation from the pan.

Throughout the cropping season, the environmental data and water level data are continuously measured and recorded to a cloud database. These data are then separated in samples such that each sample consists of the measurements between two consecutive irrigations. Twelve features were extracted from these samples. These features are minimum, maximum, mean values, and standard deviation of temperature, humidity, and pressure measurements, respectively. The average water level decrement per day for each sample was taken as the target value to be predicted by the regression models.

There are numerous regression methods in the literature and there are different principles that these methods are based on. Therefore, it is a common practice to train different regression methods on the input data to find the one that predicts the corresponding target values with minimum error.

In this work, three different regression methods, namely the Multiple Linear Regression (MLR), Regression Tree (RT), and the Support Vector Regression (SVR), have been tested on the data. Obviously, these methods analyze the data through different means. Therefore, we aim to understand the most appropriate approach for prediction of the average water level decrement using environmental data.

In order to compare these regression models, three performance metrics, namely, R^2, *RMSE*, and *MAPE* were calculated (Eqs. 2-4).

$$R^2 = 1 - \left[\sum^{n} i = 1(y_i - {}^\wedge y_i)^2 / \sum^{n} i = 1(y_i - {}^{-} y_i)2 \right] \tag{2}$$

$$RMSE = \sqrt{} \left[\sum^{n} i = 1(y_i - {}^\wedge y_i)^2 / n \right] \tag{3}$$

$$MAPE = 1/n \sum^{n} \; i = 1(\left| y_i - {}^\wedge y_i / |y_i|) \right| \tag{4}$$

In Eqs. (2-4), *n* is the number of samples used for calculation of the quantity, y_i and $^\wedge y_i$ are the actual and predicted values for the i^{th} sample. R^2 is a measure that tells what proportion of variance in the predicted variable is explained by the input variables. It is always in the range [0, 1] and a higher value is an indicator of good prediction. *RMSE* is a non-negative value and its unit is the same as the numbers used for calculating it. *RMSE* is a measure for the level of inaccuracy of the predictions and obtained by calculating the standard deviation of the errors. Unlike *RMSE* where the errors are squared, *MAPE* uses the absolute value of the errors and a percentage value which is also obtained by *MAPE*.

3. Results and discussion

3.1. Plant related results

Strawberry is an economically major crop for Turkey and the global agriculture sector with efficiently new varieties are being introduced and marketed. However, with incorrect or incomplete information especially on irrigation, encourages the increase of diseases and causes low yield. In this context, to determine the responses of watering on plants, frigo seedlings belonging to Fortuna and Rubygem strawberry varieties, which are widely used in our region, were grown under Spanish tunnels. Consequently, the most significant reactions of these plants against water were studied by applying 4 different levels of irrigation. The effects of the different irrigation regimes on yield-related parameters in ‘Rubygem’ and ‘Fortuna’ strawberry cultivars are shown in Table 1. The leaf area on the basis of cultivars increased significantly with the increasing irrigation, however, the differences on the basis of cultivars were found statistically insignificant. In this context, the highest leaf area was determined at IR125 with 4215 cm^2 $plant^{-1}$, whereas the lowest leaf area was determined to be 1359 cm^2 $plant^{-1}$ at IR50. This result was statistically significant as well when considering the decreasing amount of water. Similar results were identified in another study in the literature (Kapur et al., 2018). However, although there were no sharp differences among the irrigation regimes in the mentioned literature, irrigation levels other than IR50 were included in the same statistical group of the ‘Rubygem’ strawberry cultivar.

Table 1. Yield related parameters of strawberry varieties grown under irrigation

Irrigation Regime						
Leaf Area (cm^2)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	1507	2701	3249	4221	***2919***
	Fortuna	1211	2034	3190	4209	***2661***
Ave. Irrigation		**1359 D**	**2368 C**	**3219 B**	**4215 A**	
	LSDirr^a= 440		LSDvariety= N.S.		LSDirrxvariety= N.S.	
Yield Per Plant (gr)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	413.7	851.1	908.7	943.5	***779.3***
	Fortuna	457.9	829.3	1183.5	1021.8	***873.1***
Ave. Irrigation		**435.8 C**	**840.2 B**	**1046.1 A**	**982.7 AB**	
	LSDirr^a= 183.6		LSDvariety= N.S.		LSDirrxvariety= N.S.	
Number of Fruits per Plant (Piece)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	27.9	47.0	50.9	53.0	***44.7B***
	Fortuna	34.3	53.2	71.2	57.0	***53.9 A***
Ave. Irrigation		**31.1 B**	**50.1 A**	**61.0 A**	**55.0 A**	
	LSDirr^b= 11.4		LSDvariety^c= 8.06		LSDirrxvariety= N. S.	
Average Fruit Weight (gr)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	14.8	18.1	17.9	17.8	***17.1 A***
	Fortuna	13.3	15.5	16.7	18.0	***15.9 B***
Ave. Irrigation		***14.0 B***	***16.8 A***	***17.3 A***	***17.9A***	
	LSDirr^a= 1.24		LSDvariety^b= 0.88		LSDirrxvariety= N. S.	

Differences between the means were showed with different letters, N. S.: Not Significant, ^{a}: $p \leq 0.001$; ^{b}: $p \leq 0.01$; ^{c}: $p \leq 0.05$.

Moreover, it was reported earlier that there were significant reductions in leaf production, stomatal conductivity and the photosynthesis rate as a result of limited irrigation practices, leading to significant different responses among the genotypes (Grant et al., 2012). Consequently, it has been clearly determined that the amount of irrigation water has a significant effect on the formation and emergence of new leaves in plants

The yield values per plant, one of the most important parameters for strawberry cultivation, were determined to have been significantly affected only by the irrigation water level. Although not statistically significant, the Fortuna strawberry cultivar yielded 93.8 g more per plant. The highest yield was determined to be 1046 g plant^{-1} at IR100 which is the optimal irrigation level. This was statistically followed by IR125 (983 g plant^{-1}) in the same group. The decreasing irrigation level as well as the losses observed in the yield and vice versa the decrement of the increasing irrigation level has once again undoubtedly indicated the significance of the proper irrigation level in strawberry cultivation. Similarly, this was also mentioned by (Kapur et al., 2018) as the lowest yield of the IR50 level (397.9 g plant^{-1}), whereas no significant differences were detected in the other irrigation regimes in terms of yield, apart from the highest yield (553.8 g plant^{-1}) obtained in IR75. The reasons for obtaining different yields in the Rubygem variety against similar irrigation levels could be the prevailing climatic differences in the periods of cultivation, fertilization conditions and planting time. Also, this situation can be related with variation of nutritional status during the production season (Domínguez et al., 2020).

The number of fruits and average fruit weight values of this study that determined the amount and quality of fruit are presented in Table 1. Although the interaction between the factors studied was insignificant, the average fruit weight was significantly higher in the Rubygem cultivar (17.1 g). At this point, the Fortuna cultivar was found to be significantly higher than the Rubygem cultivar by a value of 53.9 fruits. Similarly, significant changes in the number and weight of the fruit depending on the genotype was determined earlier by (Ashrafi et al., 2016). When the effects of irrigation levels were examined, it was found that there were significant reductions in the number of fruits per plant and average fruit weight under stressed irrigation conditions (IR50).

Even if the other irrigation levels were in the same group statistically; the heaviest fruits (17.9 g) were determined in IR125 and the highest were found by 61 fruits at the IR100 irrigation level. In accordance with the results reported in (Ghaderi et al., 2015), the yield and fruit weight decreased with reduced irrigation water in our results. In addition, in this study; cultivars were found to be different in response to drought stress. Furthermore, it is known that genotypes react differently in terms of fruit size due to limited water application (Giné-Bordonaba and Terry, 2016).

The values of some properties related to vegetation under different irrigation levels were reflected in Table 2. In this context, values such as plant width, number of crown, number of leaves were significantly affected by irrigation levels. While the lowest values were determined at the IR50 level, the number of leaves in IR100 were 72.3, the number of crowns were 9.5 in IR100 and the highest plant width value was 68.3 in IR125. When the varieties were compared in terms of these characteristics, the Fortuna variety was found to be highest by 9.5 and 63.9 pieces plant^{-1} values in terms of crown number and number of leaves respectively.

The change in plant width was found to be statistically insignificant. Moreover, similarly, with decreasing irrigation, a significant decrease in the number of crowns was determined by (Kapur et al., 2018).

The results of the physiological measurements are given in Table 3. The leaf water potential (LWP) is an important parameter that reflects the water content of the plant and it is evident that both varieties show a decrease with decreasing water.

Table 2. Strawberry varieties grown under different irrigation regime green parts characteristics of post-harvest period

Irrigation Regime						
Plan t Widt	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	52.2	55.5	58.0	71.7	***59.3***
	Fortuna	41.8	56.8	65.5	64.9	***57.3***
Ave. Irrigation		**47.0 C**	**56.2 B**	**61.8 AB**	**68.3 A**	
	LSDirr^{a}= 8.64		LSDvariety= N.S.		LSDirrxvariety= N. S.	
Num ber of	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	5.3	7.3	6.3	7.3	***6.58 B***
	Fortuna	6.0	8.3	12.7	11.0	***9.50 A***
Ave. Irrigation		**5.7 B**	**7.8 AB**	**9.5 A**	**9.2 A**	
	LSDirr^{c}= 2.7		LSDvariety^{b}= 1.91		LSDirrxvariety= N. S.	
Num ber of	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	35.3	46.7	51.3	63.0	***49.1 B***
	Fortuna	33.3	49.7	93.3	79.3	***63.9 A***
Ave. Irrigation		**34.3 B**	**48.2 B**	**72.3 A**	**71.2 A**	
	LSDirr^{b}= 17.9		LSDvariety^{c}= 12.7		LSDirrxvariety= N. S.	

Differences between the means were showed with different letters; N. S.: Not Significant, ^{a}*:* $p \leq 0.001$*;* ^{b}*:* $p \leq 0.01$*;* ^{c}*:* $p \leq 0.05$*.*

Table 3. Physiological parameters of strawberry cultivars grown under different irrigation regimes

Period									
	Irrigation Level	*Variety*	***1***	***2***	***3***	***Irrigation x Variety***	***Irrigation average***	*Variety*	***Variety average***
LWP (bar)	**50**	**Rubygem**	-16.2 ef	-24.2 m	22.3 i	**-20.9 G**	-21.7 D	**Rubygem**	**-16.7A**
		Fortuna	-20.3j	-25.2 n	-22.1 i	**-22.5 H**			
	75	**Rubygem**	-14.1 c	-19.3 I	-17.3 g	**-16.9 E**	-17.9 C		
		Fortuna	-18.0 h	-21.2 k	-17.3 g	**-18.8 F**			
	100	**Rubygem**	-12.6 b	-18.0 h	-16.0 e	**-15.5 c**	-16.1 B	**Fortuna**	**-18.3B**
		Fortuna	-14.3 c	-19.0	-16.4 f	**-16.6 D**			
	125	**Rubygem**	-11.2 a	-15.3	-14.1 c	**-13.5 A**	-14.4A		
		Fortuna	-12.7 b	-17.7 h	-15.1 d	**-15.2 B**			
Term Average			-14.9 A	-19.9 C	-17.6 B				
LSD period ^{a}: 0.06; LSD irrigation ^{a}:0.14; LSD period x irrigation ^{a}: 0.25; LSD variety ^{a}:0.10; LSD variety x period ^{a}: 0.17; LSD irrigation x variety ^{a}: 0.20; LSD irrigation x variety x period ^{a}: 0.35									
	Irrigation Level	*Variety*	***1***	***2***	***3***	***Irrigation x Variety***	***Irrigation average***	*Variety*	***Variety average***
Pn (µmol CO$_2$m^{-2}s^{-1})	**50**	**Rubygem**	5.9 i	4.9 j	4.1 j	**4.9 G**	5.7 D	**Rubygem**	**9.1 B**
		Fortuna	6.1 hi	7.0 fgh	6.1 hi	**6.4 F**			
	75	**Rubygem**	7.2 fg	6.4 ghi	7.5 ef	**7.0 E**	7.9 C		
		Fortuna	10.3 d	9.6 d	6.4 ghi	**8.8 D**			
	100	**Rubygem**	14.5 b	13.1 c	8.4 e	**11.9 C**	12.5 B	**Fortuna**	**10.4 A**
		Fortuna	13.6 bc	15.6 a	9.8 d	**13.0 AB**			
	125	**Rubygem**	13.9 bc	13.7 bc	10.1 d	**12.6 BC**	12.9 A		
		Fortuna	13.9 bc	16.1 a	10.0 d	**13.3 A**			
Term Average			10.7 A	10.8 A	7.8 B				
LSD period ^{a}: 0.37; LSD irrigation ^{a}:0.42; LSD period x irrigation ^{a}: 0.74; LSD variety ^{a}:0.30 LSD variety x period ^{a}: 0.36; LSD irrigation x variety ^{a}: 0.60; LSD irrigation x variety x period ^{a}: 1.05									
	Irrigation Level	*Variety*	*1*	*2*	*3*	*Irrigation x Variety*	*Irrigation average*	*Variety*	*Variety average*
Sc (µmol H$_2$O/m/S)	**50**	**Rubygem**	0.22	0.20	0.16	**0.20**	0.20 D	**Rubygem**	**0.31 B**
		Fortuna	0.21	0.24	0.18	**0.21**			
	75	**Rubygem**	0.31	0.26	0.28	**0.28**	0.30 C		
		Fortuna	0.32	0.38	0.27	**0.32**			
	100	**Rubygem**	0.37	0.37	0.32	**0.35**	0.37 B	**Fortuna**	**0.33 A**
		Fortuna	0.35	0.48	0.32	**0.38**			
	125	**Rubygem**	0.39	0.45	0.38	**0.41**	0.41 A		
		Fortuna	0.39	0.49	0.36	**0.41**			
Term Average			0.32 B	0.36 A	0.28 C				
LSD period ^{a}: 0.017; LSD irrigation ^{a}:0.019; LSD period x irrigation ^{b}: 0.034; LSD variety^{b}: 0.014 LSD variety x period ^{a}: 0.024; LSD irrigation x variety: N. S.; LSDirrigation x variety x period: N. S.									

Differences between the means were showed with different letters; N.S.: Not Significant, ^{a}*:* $p \leq 0.001$*;* ^{b}*:* $p \leq 0.01$*;* ^{c}*:* $p \leq 0.05$*.*

In this context, it was stated that the applied lower levels of water in strawberry cultivars examined in previous studies caused a significant decrease in the leaf water potential (Grant et al., 2012; Liu et al., 2007; Klamkowski and Treder, 2008). In addition, if the amount of water in the growing medium of the plants is less than needed, water loss is reported to occur by transpiration from the plant tissues, reducing the leaf water potential value (Blanke and Cooke, 2004). When the interaction of the Rubygem and Fortuna strawberry cultivars with irrigation was examined, the highest LWP value was -13.5 and -15.2 bar in the IR125 application, and -20.9 and -22.5 bar in IR50, respectively. When the varieties were compared, it was found that the Rubygem variety had lower response to water stress, and a higher LWP content. The Rubygem LWP value had approximately a 10% higher leaf water content. The lowest water content of the leaf was determined at the end of April, which is the 2nd measurement period in which the plant continues to develop effectively. Short after this period, the frequency of irrigation applications was increased and the LWP content increased compared to the previous stages.

Stomatal conductivity (Sc) is one of the major parameters that can be used to understand the plant's internal water condition, such as the leaf water potential. Subsequently, Sc is widely used as an important eco-physiological parameter in environmental stress studies concerning water stress. The Sc variation of the cultivars and different applications (different irrigation levels) during the plant development period is given in Table 3. The stomatal conductivity of Fortuna was measured higher than Rubygem by approximately 7%. Stomatal conductivity was significantly affected by irrigation levels for both cultivars. With the increase of the applied water, Sc increased from 0.20 to 0.41 H_2O m^{-1} s^{-1}. Irrigation and cultivar interactions were examined statistically significant at IR125 and IR50 applications for Rubygem (51%) and Fortuna (49%) Sc reductions. It was earlier reported that in four strawberry varieties, the reduced irrigation (65% of irrigation water requirement) compared to full irrigation resulted in significant reductions in stomatal conductivity (Grant et al., 2012). This is in harmony with the results of our study. Sc, which has a significant periodical change in statistical terms, increased in April when plant growth was at the highest level. This explains why the LWP value was the lowest in the same period.

The Fortuna strawberry cultivar has significantly higher stomatal conductivity, causing higher photosynthesis (Pn) than the Rubygem (14% more). In this context, the difference in Pn can be shown as the reason for the Fortuna yield which is approximately 100 g more per plant than Rubygem. The reduction of irrigation water was found to significantly reduce photosynthesis by reducing the Sc. In a similar study it was reported that water stress in cucumber reduced photosynthesis by reducing stomatal conductivity (Najarian et al., 2018). The highest Pn value in irrigation and cultivar interaction, which is statistically significant, was 13.3 CO_2 $m^{-2}s^{-1}$ in the Fortuna IR100 application, whereas the lowest was measured in Rubygem IR50 as 4.9 CO_2 $m^{-2}s^{-1}$. The comparison of the average Pn measurements of IR125 and IR50, revealed the decrease of the Rubygem strawberry cultivar by approximately 69 g yield per unit Pn, whereas the decrease in the Fortuna cultivar was less (82 g). This reflected the higher endurance of the Fortuna cultivar against the decrease of photosynthesis under water stress.

The fruits were analyzed according to their qualities as shown in Table 4. Fruits belonging to cultivars were divided into 3 classes in terms of quality. The 1st quality fruits were classified according to their diameters as 30-35 mm and above, the 2nd quality fruits were 22-30 mm and the 3rd quality were the 22 mm and below. According to the results, while the difference between cultivars and cultivar x irrigation interactions was statistically insignificant, the irrigation regimes significantly affected fruit quality.

Table 4. Fruit quality classification in strawberry cultivars grown under different irrigation regimes

Irrigation Regime						
Rate of first quality fruit (%)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	18.2	86.0	85.1	85.2	***68.6***
	Fortuna	18.2	86.0	85.1	85.2	***68.6***
Ave. Irrigation		**26.9 B**	**82.2 A**	**83.5 A**	**80.7 A**	**26.9 B**
	LSDirr[b]= 18.3		LSDvariety= N.S.		LSDirrxvariety= N. S.	
Rate of second quality fruit (%)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	46.8	11.7	13.1	14.4	***26.8***
	Fortuna	52.5	14.0	16.9	23.7	***21.5***
Ave. Irrigation		**49.6 A**	**12.9 B**	**14.9 B**	**19.0 B**	**49.6 A**
	LSDirr[c]=14.2		LSDvariety= N. S.		LSDirrxvariety= N. S.	
Rate of third quality fruit (%)	***Variety***	***50***	***75***	***100***	***125***	***Variety Average***
	Rubygem	34.9	2.3	1.8	0.4	***9.9***
	Fortuna	11.9	7.6	1.1	0.1	***5.2***
Ave. Irrigation		**23.5 A**	**4.9 B**	**1.5 B**	**0.3 B**	**23.5 A**
	LSDirr[b]= 9.6		LSDvariety[c]= N.S.		LSDirrxvariety= N. S.	

Differences between the means were showed with different letters. N.S.: Not Significant, [a]: $p \le 0.001$; [b]: $p \le 0.01$; [c]: $p \le 0.05$.

In this context, while the first quality fruit ratio decreased significantly in the 50% irrigation regime, this value varied from 80.7% (IR 125) to 83.5% (IR 100) in the other irrigation regimes when considered in the same statistical group. Thus, the results revealed that the 75% irrigation regime was optimal for producers, in which water consumption was partially reduced with no reduction in the ratio of the 1st quality fruits.

3.2. Regression analysis results

The results obtained through the regression methods are given in Table 5. As can be seen from the table, the RT method has the lowest *RMSE* and highest R^2 and *MAPE* values. This means that RT is a more suitable tool for modeling pan evaporation using environmental data.

Table 5. Regression results of MLR, RT and SVR methods

	R^2	*RMSE*	*MAPE*
MLR	0.7109	1.0355	0.2726
RT	**0.7793**	**0.9048**	**0.1953**
SVR	0.6930	1.0671	0.2447

The comparison of the RT predictions with actual values are shown in Fig. 4. The correctness of the predictions is higher in the locations where the daily pan evaporation as well as the difference between consecutive irrigations are lower. Particularly, the prediction performance of the model decreases after irrigation no 23.

These irrigations correspond to times when the daily average temperature is higher than the earlier irrigations. It should also be noted that for the irrigations with high pan evaporation, the model is able to predict a maximum value around five. The reason for observing such a prediction is related with pruning of the RT model. Higher predicted values could have been obtained by applying smaller amount of pruning to the RT. However, in that case the generalization ability of the model is lost possibly causing overfitting eventually.

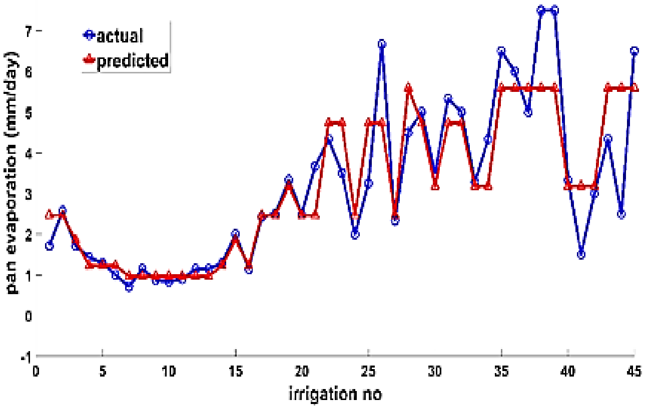


Fig. 4. Comparison of actual and predicted values for regression tree method

4. Conclusions

In this study, an automated irrigation system featuring internet connection and a smart phone application is developed. Performance of the system has been tested on cultivation of strawberries. Effects of different irrigation levels on plants has been exhaustively investigated by analyzing various parameters of plants and fruits. Also, using the environmental data collected inside the greenhouse, regression analysis has been performed to predict daily pan evaporation. In conclusion for the application of different irrigation levels on plants, it is clearly seen that the water stress has a negative effect on the physiological parameters. In this context, it has been found that the yield changes in the same direction with the effect of the mentioned parameters.

The Fortuna variety is less affected by water stress compared to Rubygem. Moreover, the irrigation factor alone has a significant effect on yield and fruit quality parameters. Especially, at the IR50 irrigation level, the first quality fruit level decreases significantly, the second and third quality levels are obtained at the highest rates. The effect of applied water amount on yield, fruit quality and, plant vegetative parts were obviously observed and the reasons of these differences were clearly explained by eco-physiological measurement such as LWP, Pn and Sc. As a result of this research; to reach desired yield and fruit quality, amount of irrigation water was found pivotal for strawberry cultivation.

According to the results obtained from the regression analysis, it can be concluded that the RT method is more suitable for prediction of pan evaporation inside a high tunnel greenhouse. Through such a prediction, it becomes possible to calculate the amount of water required for irrigation prior to using weather forecast data.

In all three methods, a lower prediction accuracy is observed when daily evaporation is higher. This situation may be overcome by generating different models for these data. However, such an application requires more data to be collected for longer periods. Considering all the obtained results, one major benefit of the system can be the elimination of manual labor in the calculation of the irrigation duration and turning on/off the solenoid valves. Furthermore, the system makes it possible to control the valves from remote locations.

Therefore, the presence of an operator in the field is not required during the irrigation process. As a result, the human-related mistakes as well as the labor time required for an irrigation are reduced. Finally, the involved sensors allow for collection of in-field data, which can be used for development of advanced algorithms for an adaptive irrigation system.

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