The Journal of Animal & Plant Sciences, 26(1): 2016, Page: 131-138
ISSN: 1018-7081

DRIP IRRIGATION AUTOMATION WITH A WATER LEVEL SENSING SYSTEM IN A GREENHOUSE

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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, drip irrigation system automatically governed irrigation in accordance with a water level sensing system in the mini-pan with the help of evaporation. Data acquisition was performed by an electronic circuit, which processed data and then sent the data to the microcontroller (Pic16f877). In the system, a closed loop control system based on sensing water level in the mini-pan was used to activate irrigation, thereby the system started irrigation whenever water level in the mini-pan dropped to the set level. The performance of the automated system can be increased as the irrigation timing in the software is adjusted according to plant growth stages.

Key words : automated irrigation, drip irrigation, water level sensor, irrigation controller,mini-pan.

INTRODUCTION

Pressurized irrigation systems when combining by an automation systems have become more effective in irrigation practices. Nowadays, the current trend has been swithcing from a manual system to automatic operations in a pressurized system and also that automation and electronics in agriculture become more popular all around the world (Josi and Gokhale, 2006). Energy savings, reduced labor cost and control in fertilizer application are among some of the major advantages in adopting auotomated techniques in drip irrigation systems (Yildirim and Demirel, 2011). Automated irrigation systems provide high crop yield, save water usage (Mulas ,1986), facilitate high frequency and low volume irrigation (Abraham *et al*. 2000), and also reduce human errors (Castanon, 1992). Many methods have been described and sensors developed to manage irrigation systems objectively (Salas and Urrestarazu, 2001). Recent irrigation technologies have used sophisticated equipment to supply water to the root area of plants as they need it. However, the use of these sophisticated methods is not possible for all growers. A simple irrigation system, called the irrigation control tray, was developed by Caceres *et al.* (2007), which activated the irrigation system with the aid of a level-control relay. Gieling (1995) stated that automation systems should be used both to measure the enviromental conditions and to use in irrigation. Irrigation can be performed according to the methods of solar radiation and Class-A pan. Class-A pan has been used succesfully in all over the world to estimate evapotranspiration. Hanan (1990) reported that Class-A pan used in an greenhouse to estimate evapotranspiration has achieved the similar results as musch as the methods of radiation (FAO) and Priestley-Taylor. Jain (1975) and Sharma *et al.* (1975) stated Class-A pan is not appropriate for farmers to be used in an open field, so that they used a mini-pan (10.5 cm in diameter and 13.5 cm in height) to irrigate wheat and maize in an open field and obtained the correlation coefficient of 0.82 between mini-pan and Class-A pan. Palacios and Quevedo (1996) used a mini-pan consisting of double ring (the inner ring was 27.5 cm in diameter and 7.5 cm in height, the outer ring 55 cm in diameter and 22 cm in height) to schedule the irrigation program in an open field and reported to be used for irrigation. Cemek *et al.*(2004) observed a strong relationship between mini-pan and Class-A pan.

The objective of this study was to test a prototype of a mini-pan and a water level sensor and also to modify the irrigation controller, triggered by the water level sensor in the pan, and thereby develop a simple and economical automated irrigation system appropriate for greenhouse growing of high-value crops.

MATERIALS AND METHODS

The experiment was conducted outdoor of a greenhouse from May to August, 2011 at Canakkale Onsekiz Mart University, Turkey. The geographical location of the experimental area is 40°06'32.64" N latitude, 26°24'45.31" E longtitude, and has a 5-m elevation (Figure 1).

Figure 1. Geographical location of experimental site.

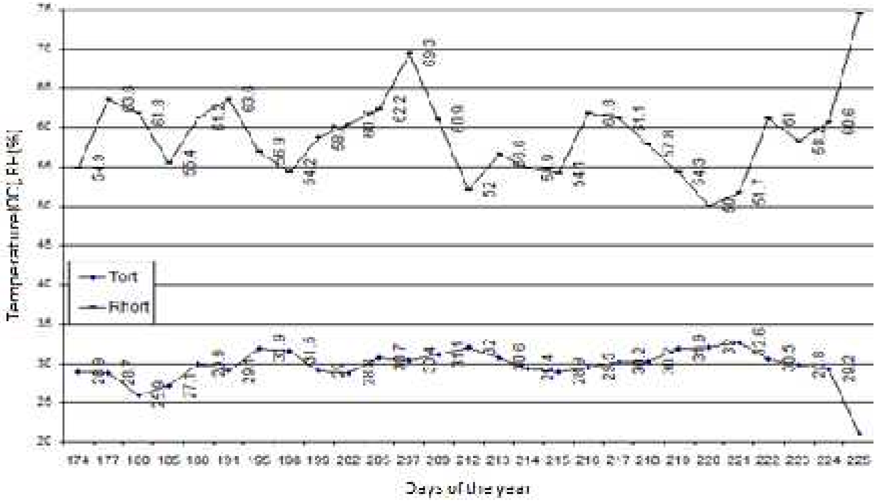

Figure 2. Meteorological data for period of experiment

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 (Figure 2), and measurement range was from -20 ^{0}C to 70 ^{0}C for temperature, 5% to 95% for humidity.

The quality of the irrigation water is given in table 1. A standard soil must have a pH value between 6.5 and 7.2 and electrical conductivity (EC) of less than 4 mS cm^{-1} (Ayers and Westcot, 1994). According to these values, the salinity level of the substrate was in the normal range. The irrigation water, however, was in the moderately tolerable range; it had already been used for irrigation at the site. Each pot in the experiment was applied with the same amount of fertilizers: triple super phosphate (3 g per pot), potassium sulfate (3 g per pot) and urea (3 g per pot). Urea was applied again at 15 and 20 day intervals respectively after planting at the same dosage.

Table 1. Quality of irrigation water used in the experiment.

pH	Na %	EC mS cm^{-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

SAR = Sodium adsorption ratio, RSC = Residual sodium carbonate, me = miliequivalents

Components of the automated irrigation system: Nurseries planted with peppers (*Capsicum annuum* L.) were transplanted into pots. The substrate was a mixture of peat (1:4, v/v) and soil (3:4, v/v).), each pot contained 4L of substrate and the layout of the experiment's components is given in figure 3. The irrigation system included the following components; water storage tank (50 L); one of it was to irrigate , another one was to fill the mini-pan, submersible pump operating at 12 vdc(volts direct current) in each storage tank and 2.05A, power supply (12 vdc), pots (250x210 mm, 9 L) having a pan under it to collect water that drains, Ø16 pipes with drippers (4 L/h) at a spacing of 33 cm, with one dripper serving each pot. Valves and connection apparatus were used to integrate all items of the irrigation system. Mini-pan was consisting of double rings, the height of both was 20 cm, the inner ring diameter of 27 cm and the outer of 32 cm, also there was a notch at the bottom of inner ring providing water movement between them. The sensor determining the amount of allowable water to evaporate was installed inside in the inner ring. The top tube was welded to the upper point of the mini-pan to fill it and water was pumped by the irrigation controller from storage tank, when the allowable amount of water was evaporated from mini-pan. The drainage pipe was removing excess water to fix the top water level in the mini-pan to 13.5 cm after each filling process as seen figure 4.

Figure 3. Layout of the experiment's components(a) and irrigation controller (b).

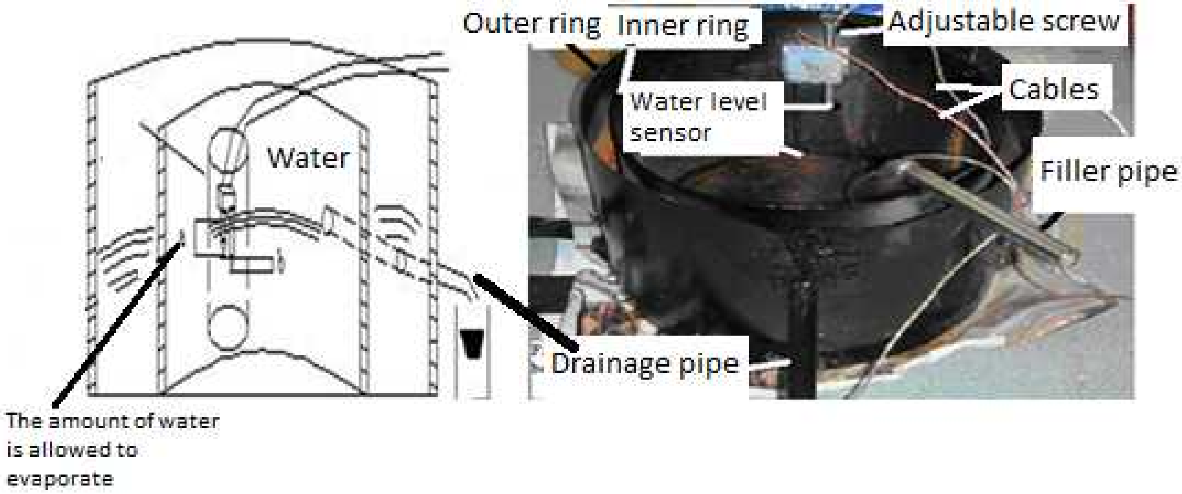

Figure 4. Mini-pan and its components.

The most important and basic component of the automated irrigation system was the sensor, which detected the water level in the mini-pan. It was made of two steel rods, one rod fixed and screw one was moving up and down to adjust the amount of water allowed to evaporate. The distance between the rods was 2.5 cm. They were placed in a plastic box (width 3x3 cm, height 1 cm), then filled with silicone. At the end of the rods, the cable was connected to provide an electrical communication between the rods and the MCU (Fig. 5).

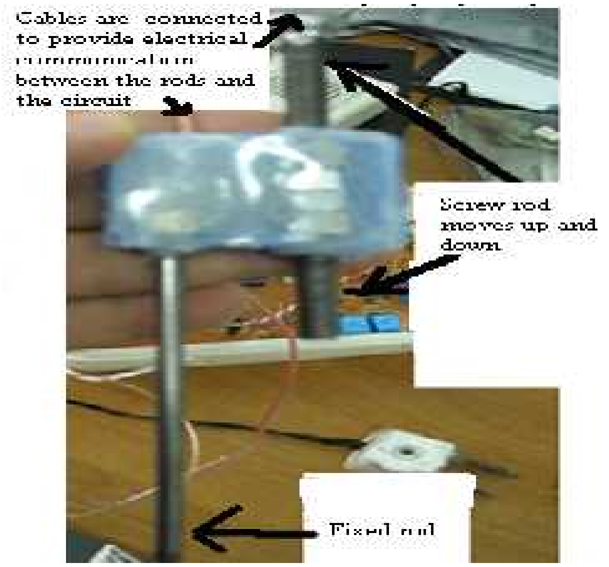

Figure: 5. View of the sensor determining the amount of water allowed to evaporate

A signal coming from the water level sensor was sent to the Microcontroller unit (MCU-Pic16F877) and then irrigation started and stopped according to the logic embedded in MCU. The circuit included both a buzzer to give a warning voice and an LCD to show some messages such as “1.pump run” or “2.pump run” etc. The MCU unit is a device that has programmable capability, read sensor, and controls the devices such as relays connected to the pumps(fig 3). In this experiment, the MCU was actually a controller, upon receiving a signal from the water level sensor it runs the pumps and shuts down after the procedure. The MCU has a 20 Mhz pic processor with 40-pin Dual In-line package (DIP) and runs at a relatively low voltage value of 5 vdc (Altınbasak, 2004). One pin of the MCU was assigned as an input to monitor the water level in the mini-pan in each second for all day and throughout the entire experiment. Even though circuit has 4 relays, two pins of the MCU were assigned as output pins both to pump water to the root area of the plants and to pump water to fill the mini-pan.

Controller software: The irrigation controller program was written using the PicBasic Pro software program and the general strategy for the automated irrigation defined in the logic was loaded into the memory of the MCU. Hence, the logic of the irrigation strategy was defined in the MCU, having a memory of 2K, which then took over and made detailed decisions on when to apply water and how much water to apply. The dosage of water to be applied was determined according to the pumping time of water to refill the root zone as water level in the mini-pan dropped the threshold level. In the system, the feedback and control were done constantly, depending on the feedback from the sensor. Whenever a signal was sent to the MCU, the irrigation actions were carried out during the whole experiment period. Data flow diagram in the software is given in figure 6. The top water level in the mini-pan was 13.5 cm, and a signal was produced whenever the level dropped to 12 cm, then the MCU started irrigation and first, ran the irrigation pump for 15 minutes and second, filled the mini-pan. After completing these processes, it checked whether the mini-pan full or not. if yes, it went to back to read the sensor. If not, it sent the message “the system is out of order, please check” on LCD (Fig. 6).

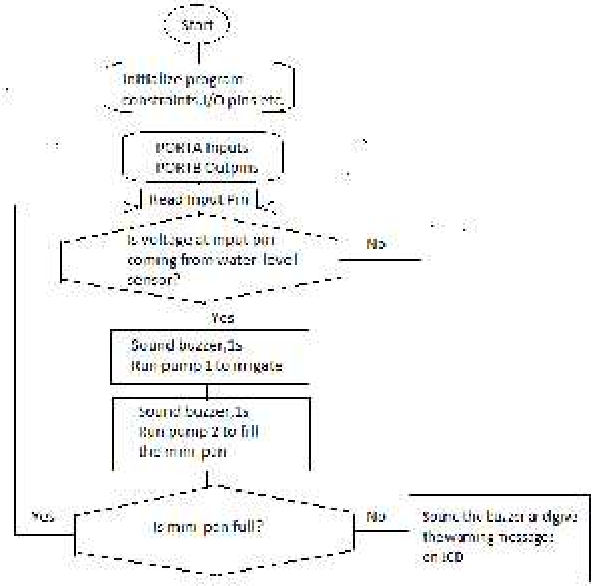

Figure: 6. Flow diagram of controller software program in the MCU

Irrigation applications: The irrigation treatments were arranged as follows: the required time (15 minutes) for pumping water to the root area of the plant as 30% of available soil moisture was depleted was the time required to raise moisture content of the substrate up to field capacity (FC) in each irrigation. After each irrigation, all pots were weighed manually, then the water quantities were determined by weight of the pots intended to identify evapotranspiration. Daily evapotranspiration (ET) was estimated by using the water balance method between the two irrigations (Yıldırım and Demirel, 2011).

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

Where: ET is the evapotranspiration (mm), W_{i-1} and W_i mass (kg) of the pot at day i-1 and i, 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).

Plant and fruit development parameters were observed for each plant in the treatment. Weights in gram for stem, leaf, etc. were determined by using a sensitive weighing (0.01g).

RESULTS AND DISCUSSION

Fruit development and vegetative growth parameters were given in table 2. Even though mean fruit weight was similar to the literature, stem and leaf weight and leaf area of pepper were slightly lower than the values given for these by Yildirim (2010) and Yildirim and Demirel (2011). The action of root zone depletion and the timing of the irrigation events throughout the calendar days are shown in figure 7. The irrigation events were performed successfully between 165 and 184 days of the year as seen in fig 7, since the MCU activated the pumps whenever water level dropped to 12 cm in the mini-pan. The controller unit, however, couldn't activate the pumps on the 185th, 195th, 212nd calendar days, even water level was below 12 cm. The reason of that was an adhesion of a small piece of straw to the adjustable rod, providing a connection between water and rod. That's why, the sensor failed to produce a signal to be sent to the MCU. However, after removing the straw, the system has fulfilled its responsibilities successfully. Therefore, the average pot weights dropped up to 5146 g on the 185th day of the year.

Table: 2. Plant development parameters

Sampling date	12 June 2012		06 July 2012		28 August 2012	
	Fresh	Dry	Fresh	Dry	Fresh	Dry
Mean Fruit weight (g)	-	-	2.57	0.19	7.37	0.5
Stem weight(g)	0.58	0.13	4.8	1.0	30	6
Leaf weight(g)	1.30	0.12	25.5	4.81	30	7
Leaf area (cm2)	32.3		1324		2161	

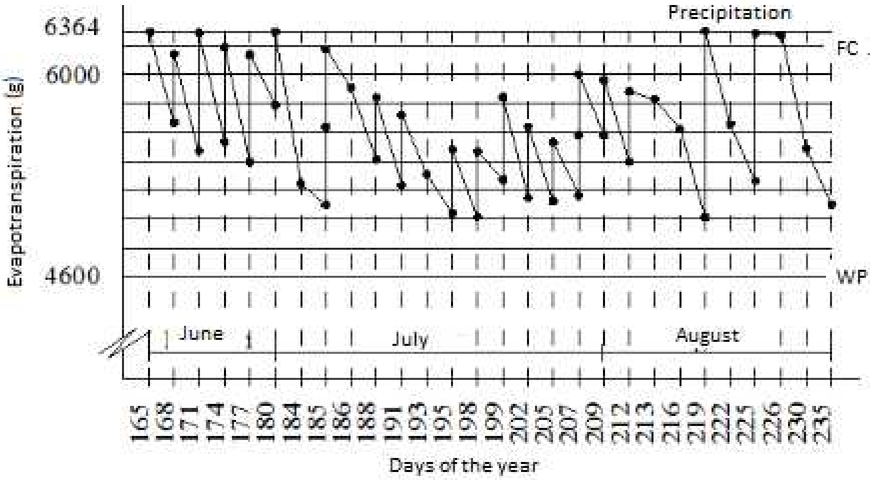

Figure: 7. Changes in moisture content in the substrate, implemented by irrigation controller

Water was applied according to the pre-set strategy by the automated system whenever water level in the mini-pan dropped to 12 cm, and the system met the water demand of plants till 185th day of the year. However, irrigation couldn't be initiated by the system on the 185th day, even though water level in the mini-pan fell up to 11 cm and soil moisture level in the substrate dropped up to 5146 g also. By taking the straw away from the mini-pan, the MCU initiated irrigation and brought the pots to the weight of 6200 g and increased the water level to 13.5 cm in the mini-pan. Because of the high evaporation in July, the water in the mini-pan that allowed to evaporate was adjusted from 15 mm to 10 mm by the screw rod and irrigation started when evaporation occurs 10 mm after the calendar day of 188th . Evaporation amounts and days on when irrigation events were activated are given in figure 8. As seen in fig 8, the system performed irrigation activities successfully according to the identified strategy, since the water level in the mini pan was increased to 13.5 cm at regular intervals and this time irrigation was activated when the water level fell to 12.5 cm. The substrate moisture level in the substrate after and before irrigation is given in figure 8. Even though the system run successfully according to the identified strategy, the substrate moisture level in plant roots remained below 6000 g which was caused by the definitions of the fixed run time of the irrigation pump to the MCU, as 15 minutes. The moisture level after and before irrigation seems to parallel to each other in fig 9. It is obvious that the moisture level in the substrate started decreasing in a stepwise manner after the 185 days of the year. Stress development in pepper plants began at this time and reached to the top level on the 199 days of the year due to the lack of water of 200 g. if irrigation timing was increased in a step manner from 15 minutes to 21 minutes after 185 days of the year up to the 199 days of the year, the performance of the system would be very higher than the existing condition

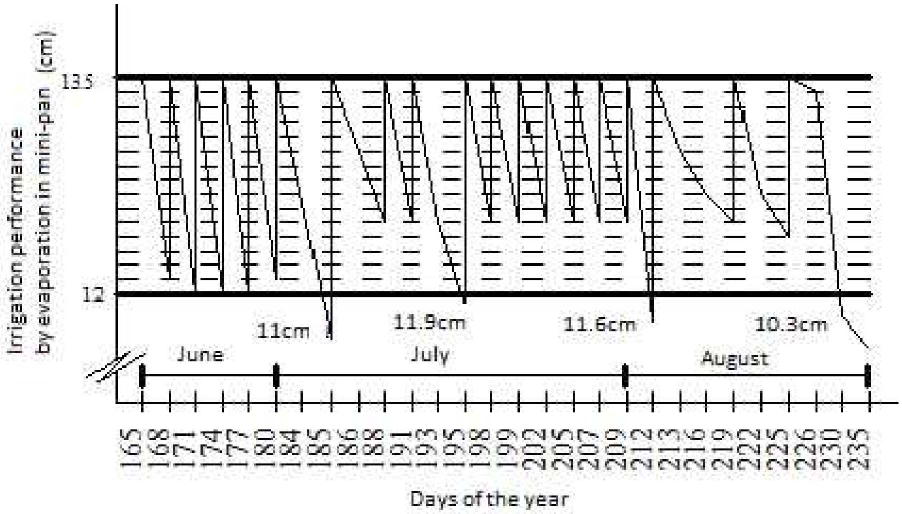

Figure: 8. Irrigation activities by evaporation in the mini-pan

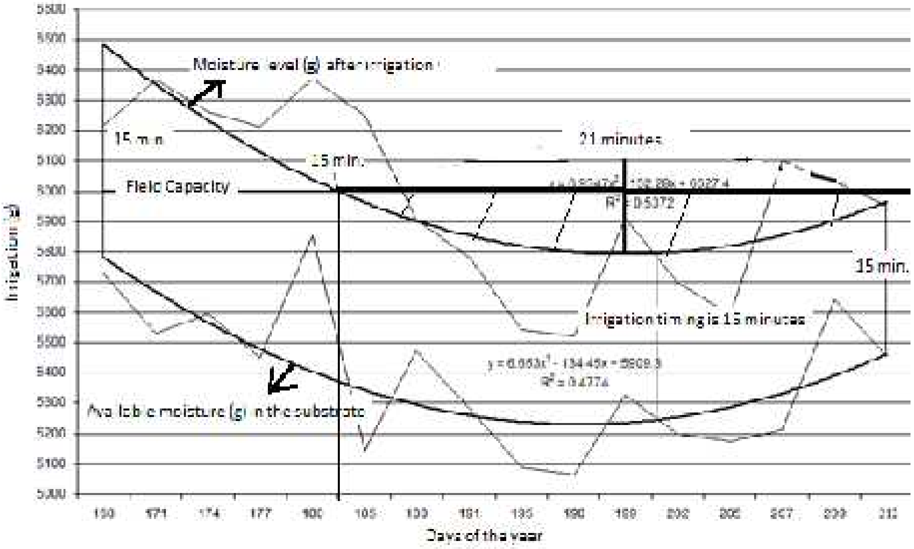

Figure: 9. Irrigation performance during the experiment

The relationships between the Class-A pan and mini-pan were given in figure 10. The amounts of evaporation in Class-A pan from June to August were 159.9, 294.1 and 61.5 mm, respectively, but those of that in the mini-pan reduced to 88.8, 127.6 and 27 mm for same months, respectively. Therefore, the correlation coefficient between Class-A pan and mini-pan were r^2=0.50, which was lower than the values given in the literature. The main reason of less evaporation in the mini-pan was to place it next to the plants, which caused a reduction in the amount of evaporation by shading the mini-pan.

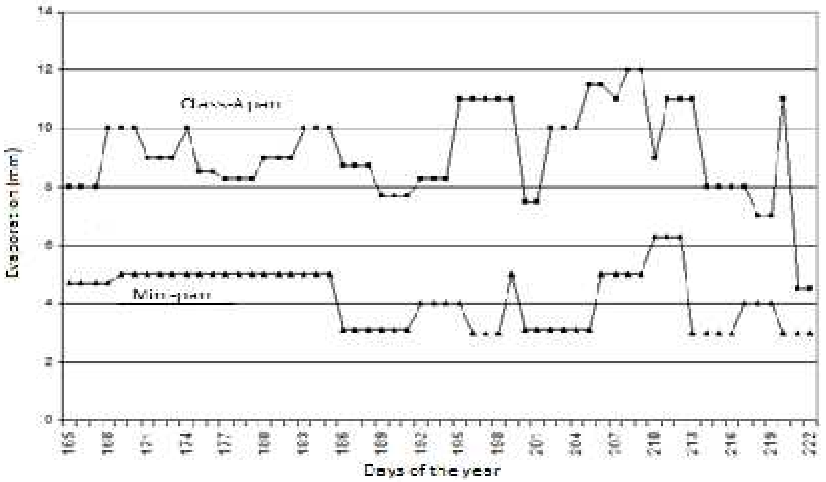

Figure: 10. Evaporation amounts in both Class-A pan and Mini-pan

Cemek *et al.* (2004) identified the correlation coefficient of evaporation occurring Class-A pan and mini-pan as 0.81. Palacios and Quevedo (1996) reported that mini-pan can be used in irrigation scheduling. Jain (1975) and Sharma *et al.* (1975) found the correlation coefficient between Class-A pan and mini-pan as 0.82, and they used a mini-pan successfully in corn and wheat irrigation in open field.

The prototype of the irrigation controller was tested to determine both the controller unit, sensor and software performances. In this experiment, once the general strategy was defined by the MCU, it took over and made decisions about when to apply water and how much water to apply. Yildirim and Demirel (2011) developed an irrigation controller and reported that the most important points in the automated drip irrigation system are sensor calibration and installation of the soil moisture sensor in the pot. In the experiment, depending on the feedback of the water level sensor, the irrigation decision was made and actions were carried out throughout the entire experiment. However, plant development parameters were lower than the values given in the literature, since the irrigation timing in the software used in the experiment was simple. Therefore, irrigation timing should be defined into algorithm according to the plant growth period and the location of the mini-pan is so important, since evaporation is greatly affected when it has been under the shadow of pepper plants and doesn't reflect the evapotranspiration. When this system is used in a greenhouse, irrigation timing must be arranged according to the plant growth periods.

Acknowledgements: The author is grateful for the financing of the study to Scientific Support Program of Canakkale Onsekiz Mart University in Turkey, Research Project Reference No: BAP (2011-45). I also like to thank the Canakkale Onsekiz Mart Agricultural Experiment Station for their assistance of this research and thanks to unknown reviewers for their valuable recommendations for this paper.

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