ÇOMÜ Zir. Fak. Derg. (COMU J. Agric. Fac.)
2024: 12(1): 1-10
ISSN: 2147–8384 / e-ISSN: 2564–6826
doi: 10.33202/comuagri.1472578

Research Article

A Closed Loop Automated Drip Irrigation System Based on Arduino Uno

İsmail Aktürk[1] **Mert Koparan**[1] **Murat Yıldırım**[2*] **Umut Mucan**[2]

[1]Senior students, Canakkale Onsekiz Mart Universty, Agricultural Faculty,Agricultural Structures and Irrigation Department, Canakkale, Türkiye
[2] Canakkale Onsekiz Mart Universty, Agricultural Faculty, Agricultural Structures and Irrigation Department, Canakkale, Türkiye
*Correspondence author: myildirim@comu.edu.tr

Received Date: 25.04.2024 Accepted Date: 09.07.2024

Abstract

In recent years, the limited availability of irrigation water has made the optimal use of water a necessity. Successful irrigation practices in agriculture reduce excessive water usage and increase water use efficiency. Economical use of water can be made possible through modern irrigation systems. Nowadays, automatic control systems in agriculture have made significant progress and offer important advantages.

In this study, a mini evaporation pan consisting of nested two cylinders was used (outer cylinder diameter 32 cm, inner cylinder diameter 27 cm, and both with a height of 20 cm) and the water remained at a constant level in both cylinders due to the notch beneath the inner cylinder. A water level sensor was placed inside the inner cylinder, and irrigation was activated based on the signal received from the sensor. The data from the sensor was processed by the microcontroller on the Arduino Uno, and three different irrigation applications were implemented by activating pumps connected to relays at 07:00, 14:00, and 21:00 o'clock, and then the mini-evaporation pan was refilled, and the system waited for the next irrigation period.

The automation drip irrigation system-maintained irrigation as a closed loop throughout the entire growth period of the lettuce plants using this approach. The addition of a fertilization unit to this system could make it more effective in plant production. The performance of the system will be significantly enhanced by enabling hardware that provides irrigation and fertilization to the plant according to its specific needs in terms of timing and quantity, along with appropriate software integration.

Keywords: Lactuca Sativa, Automatic drip irrigation system, Water level sensor, Mini evaporation pan, Arduino Uno

Arduino Uno Tabanlı Kapalı Döngü Otomatik Damla Sulama Sistemi

Öz

Günümüzde sulama suyunun kısıtlı bir kaynak olması, suyun optimum kullanımını zorunlu bir hale getirmiştir. Tarımda bilinçli bir şekilde yapılan sulama aşırı su kullanımını azaltarak su kullanım randımanını arttırmaktadır. Suyun ekonomik bir şekilde kullanılması modern sulama sistemleri ile mümkün olabilecektir. Bu günlerde, tarımda otomatik kontrol sistemleri önemli bir ilerleme kaydetmiş ve önemli avantajlar sunmaktadır.

Bu çalışmada, iç içe gecik iki silindirden meydana gelen mini buharlaşma kabı (dış silindir çapı 32 cm, içi silindir çapı 27 cm ve yüksekliği 20 cm) kullanılmıştır. Mini-buharlaşma kabı içerisine su seviye sensörü yerleştirilmiş ve sensörden gelen sinyal ile sulama aktive edilmiştir. Sensörden gelen veri Arduino uno da bulunan mikroişlemci ile işlenerek rölelere bağlı pompalar saat 07.00, 14.00 ve saat 21.00 da çalıştırılarak üç farklı sulama uygulaması gerçekleştirilmiştir. Sulamalardan sonra mini-buharlaşma kazanı doldurularak bir sonraki sulama süresi sistem tarafından beklenmiştir. Otomatik damla sulama sistemi sulamayı marul bitkisinin tüm gelişim dönemi süresince bu yaklaşımla kapalı döngü olarak sürdürmüştür.

Otomatik damla sulama sisteminin sulama performansını başarılı bir şekilde gerçekleştirmiştir. Bu sisteme gübreleme ünitesinin de eklenmesi, sistemi bitkisel üretimde daha etkili hale getirilebilir. Bitki besin elementlerinin bitkinin ihtiyaç duyduğu döneme göre uygulayacak sistemin oluşturulmasında gerekli yazılım ve donanımın sisteme eklenmesi ile oluşturulacak otomatik sulama-gübreleme ünitesi bitkisel üretimdeki başarısını önemli ölçüde arttıracaktır.

Anahtar Kelimeler: Lactuca Sativa, Otomatik damla sulama sistemi, Su seviye sensörü, Mini buharlaşma

kazanı, Arduino Uno

Introduction

In our Turkey, greenhouse cultivation activities commenced in the 1940s with the construction of research greenhouses in some agricultural establishments in our southern provinces. While there was a slow development in greenhouse cultivation between 1940 and 1960, it has been observed that greenhouse cultivation has shown a faster development after the 1970s with the use of transparent polyethylene as a covering material (Emekli et al., 2008). In our Country, 31 million tons of vegetables were produced in 2019, with 23.2 million tons coming from open agriculture and 7.8 million tons from protected cultivation. The total area of protected cultivation has reached 790,000 decares. The country's modern greenhouse assets are approximately 13,000 decares, where export-oriented production is carried out using soilless agriculture methods (Anonymous, projected to 2024a). 45% of the greenhouses in Turkey are between one and three decares in size, with only 2% exceeding ten decares. Moreover, 85% of the assets consist of low-technology plastic greenhouses.

In greenhouse cultivation, since natural rainfall cannot be utilized, irrigation emerges as the most critical input. The efficient use of irrigation water leads to labor savings, allows for the delivery of plant nutrients together with irrigation water, and provides advantages in combating weeds and diseases. These benefits make drip irrigation the preferred method in protected cultivation (Yıldırım et al., 2015).

In our country, there have been limited studies conducted in open field or greenhouse conditions regarding the irrigation of different lettuce varieties. These studies have commonly utilized irrigation programs based on soil moisture as well as those referencing the amount of water evaporated from a Class A evaporation pan (Öneş et al., 1995; Yazgan et al., 2006; Acar et al., 2008; Bozkurt et al., 2009; Çebi et al., 2014; Yıldırım et al., 2015). However, it has been observed that producers, especially those engaged in protected cultivation, have not widely adopted these methods for planning irrigation timing. Additionally, previous studies have shown that the response of irrigation practices on yield and quality can vary depending on the irrigation method, plant species and variety, as well as climatic and soil characteristics.

In plant production, automation allows producers to achieve high and quality yields. The number of producers utilizing high technology is quite low, and the use of technology remains limited among small and medium-sized producers. Both globally and in our country, numerous studies have been conducted and are ongoing on automation suitable for small and medium-sized producers. Abraham et al. (2000) implemented irrigation automation based on the electrical conductivity of soil moisture. Cacares et al. (2007) developed an extremely simple Irrigation Control Tray that can be used in greenhouse conditions, automating the irrigation process. Yıldırım and Demirel (2011) combined drip irrigation systems with automation to enable irrigation based on soil moisture. Sharma et al. (1975) utilized a mini evaporation pan (10.5 cm in diameter, 13.5 cm in height) and found a correlation coefficient of 0.82 between their mini evaporation pan and the Class A evaporation pan.

Recently, automation has been increasingly applied in both open agricultural fields and enclosed greenhouses. The integration of automation systems with solar energy has gained further importance due to its potential for labor and energy savings. Guerbaoui et al. (2013) implemented a computer-based automatic irrigation system that controlled drip irrigation and fertilization systems, applying 5670 m^3 ha^{-1} to 7000 m^3 ha^{-1} of water and achieving a water saving of 20-30%.

Anjaly (2016) compared a system that performed automatic irrigation and fertilization powered by solar energy with a manual fertilization application. The study found that in greenhouse conditions, the automatic irrigation and fertilization system achieved maximum yield in cucumber plants. The researcher noted that if energy is provided by solar panels, the system could be easily transported to different locations, offering a significant advantage.

In our study, we successfully operated a system that automatically starts and stops irrigation based on the evaporation of water from a mini evaporation pan. The system uses an electronic circuit to initiate irrigation when the water level inside the pan drops to a certain level, continuing irrigation for a set duration before automatically turning off.

Material and Methods

The research was conducted in 2023 in the unheated greenhouse located at the Dardanos research canter at Çanakkale Onsekiz Mart University. The greenhouse where the research was carried out is situated at 40° North latitude and 28° East longitude. Due to its location, Çanakkale has transitional climatic characteristics between the Mediterranean and the Black Sea. Generally, temperate can be drop below zero degrees between November and march; however, between November and March, frost events are encountered due to the drop in air temperature below zero degrees. According to the annual precipitation totals of the Çanakkale Station owned by the General Directorate of Meteorology for the period 1929–2023, the average annual precipitation is 625.3 mm (Anonymous 2024b).

The growing medium was prepared by mixing 400 g of air-dried soil through a 1mm sieve with 100 g of perlite in a 1:5 ratio to create a homogeneous mixture. This mixture was then placed in 2 L pots, and Campania (Lactuca Sativa var. campania) lettuce seedlings were transplanted into these pots on 06 Oct.2023, as given in Figure 1. Perlite was used in this study both for aeration and to increase the water retention capacity of the growing medium. Each pot was filled with this mixture and all pots were weighed, and it was almost 1430 g. The irrigation water was provided from the municipal water supply, characterized as Class 1 with an electrical conductivity of 0.25 ds m^{-1}, indicating no salinity issues.

Figure 1. Transplantation Lettuce Seedlings into Pots

To ensure equal fertilization for each pot, three stock solutions were prepared. Using a measuring cylinder, predetermined amounts of N(230ppm), P(120ppm), K(200ppm), Ca(142ppm), Mg(36ppm), Fe(5 ppm), Mn(0.5ppm), B(0.5ppm), Cu(0.02ppm), Zn(0.05ppm), and Mo(0.01ppm) were manually applied to each pot to provide the necessary major and minor elements for fertilization (Figure 2).

Figure 2. Stock solution for fertilization.

Automatic Irrigation System Components

The irrigation layout used in the experiment is illustrated in Figure 3. For each irrigation treatment, 50 L water tanks were employed, and each treatment had its own separate water tank, pump, and other apparatuses. Additionally, an independent water tank was used to replenish the water evaporated from the evaporation pan. This was achieved by refilling the pan to its maximum level using a separate submersible pump as a result of the evaporation process.

Figure 3. experimental design

The mini evaporation pan, as shown in Figure 4, consists of two nested cylinders. Both cylinders have a height of 20 cm. The outer cylinder has a diameter of 32 cm, and the inner cylinder has a diameter of 27 cm. V-shaped notches at the bottom of the inner cylinder facilitate water movement between the two cylinders. A water level sensor mounted inside the inner cylinder determines the permissible water level during evaporation. When the water level falls below the predetermined level, it generates a signal to inform the microprocessor, which then initiates the irrigation process in sequence according to the programmed instructions. After irrigation, the mini evaporation pan is refilled to its maximum level of 13.5 cm. Excess water from the pan's reservoir is drained out through a drainage channel to maintain a constant maximum water level in the mini evaporation pan. A reduction of 10 mm in the water level in the mini evaporation pan corresponds to an average decrease of 360 g in the pots during measurements. When the moisture in the pots decreases by this amount, the system initiates irrigation, supplying this volume of water to the plant root zone, thereby restoring the soil moisture to field capacity.

Figure 4. Mini evaporation pan and water level sensor (Yıldırım, 2016)

In the irrigation system, a control mechanism was established utilizing an Arduino Uno microcontroller. This was accomplished by integrating components such as the Arduino Uno, DS1302, DHT11, a water level sensor, an SD card, and a DC-DC power regulator to construct an electronic circuit, as depicted in Figure 5.

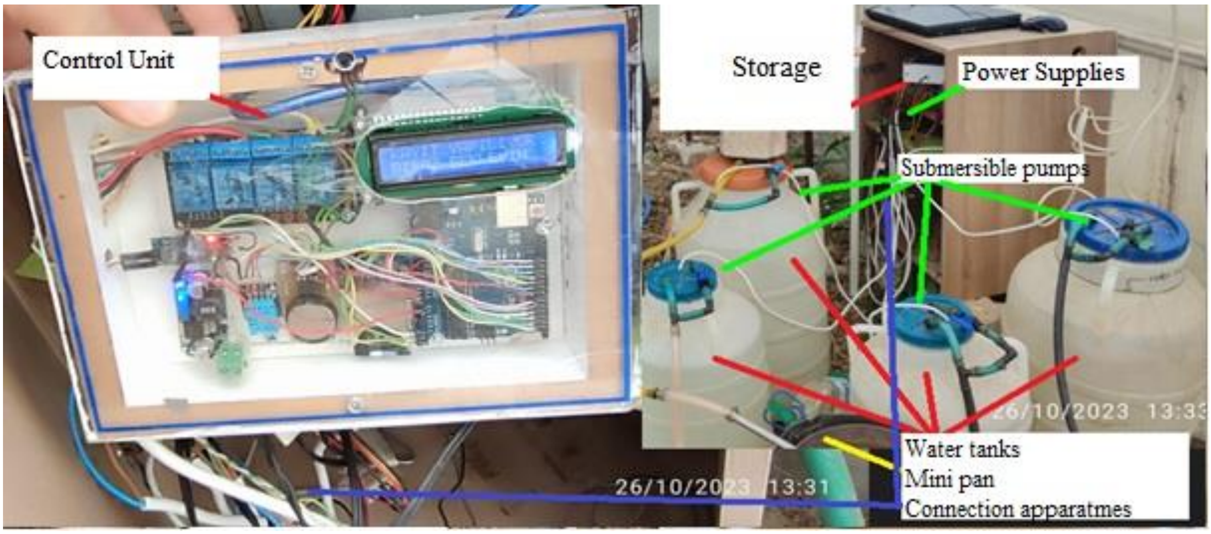

Figure 5. Control unit

In the irrigation system, a control mechanism was constructed using an Arduino Uno microcontroller. This assembly comprises components such as the Arduino Uno, DS1302 real-time clock module, DHT11 temperature and humidity sensor, water level sensor, SD card module, and a DC-DC power circuit. The schematic representation of the electronic circuit is provided in Figure 5.

Figure 6. HOBO U12 data logger to save climatic data in the greenhouse.

when the water level drops in the mini pan to the desired level, the sensor generates a signal. This signal is processed by the microcontroller, which then activates the necessary pumps for a defined duration before turning them off to await the next signal. The irrigation begins at 07:00, and after it is completed, the next irrigation starts at 12:00. The final irrigation commences at 21:00, after which the mini evaporation pan is filled to its maximum level. Subsequently, it begins to collect data from the sensor within the mini evaporation pan for the next irrigation cycle. Each irrigation was accomplished by pumps using 12 V dc submersible pumps (19 L min-1), The irrigation system incorporates Ø16 pipes and fittings.

The electrodes within the mini evaporation pan are made from metal and are positioned at two different levels. One electrode is fixed and extends to the lowest point of the pan without making contact, while the other electrode is adjustable, allowing for the customization of irrigation based on varying evaporation levels.

Irrigation

In the experiment, the seedlings transplanted into pots were manually watered for 10 days from the date of transplantation. After assembling the components of the system and installing it in the greenhouse, irrigation was conducted automatically. During the 10-day period before the transplantation of the seedlings and the installation of the system in the greenhouse, the plants were watered by hand. This established a relationship between the moisture change in the plant root zone and the rate of evaporation that would occur within the mini evaporation pan. Using the calibration curve obtained, the amount of evaporation (in mm) at the moment when 30-40% of the moisture in the soil was depleted was determined. The operation time for the pump to replenish the water depleted in the pot was programmed into the microcontroller. Based on the signal produced by the sensor in the mini evaporation pan, irrigation was initiated for each irrigation event:

Treatment 1 İrrigation event starts at 07:00.

Treatment 2 İrrigation event starts at 12:00.

Treatment 3 İrrigation event starts at 21:00.

Irrigation was carried out for the duration defined in the microcontroller for each event. The current moisture content of the plant growing medium was determined by periodically weighing the pots on a weight basis (Figure 7). The evapotranspiration (ET) between two irrigations determined by the following equation (Yurtseven et al., 2005).

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

In the given context:

- ET represents the plant water consumption in millimetres (mm).
- W_{i-1} and W_i denote the pot weights on days (i−1) and i, respectively, measured in kilograms (kg).
- I is the amount of irrigation water, measured in kilograms (kg).
- D is the amount of water, if any, that drains out, also measured in kilograms (kg).
- A stand for the surface area of the pot, measured in square meters (m²).

Figure 7. Developmental stages of plants and plant water consumption measurements in different periods

Fruit Quality Parameters

Whole plant parameters, all weights were determined using a scale with a precision of 0.01 grams, and diameter measurements were carried out with a digital caliper accurate to 0.01 millimeters (Figure 8). Leaf area measurements were conducted using a CI-202 model leaf area meter from CID, Inc, with results expressed in square centimeters (cm²). Yield was calculated on a per-plant basis, measured in kilograms per plant (kg plant^{-1}). In each plant, all leaves were detached from the stem, and the total leaf area of each plant was measured using the leaf area meter, while the weights of the leaves and the stem were separately determined using a precision scale. The values obtained from the experiment were analyzed using the SPSS statistical software package. An ANOVA test was applied to assess the significance of differences among groups, and when differences were found to be significant, the Duncan test was used to identify these differences.

Figure 8. Determination of physical and chemical parameters in the plant

Results

The quantities of irrigation water applied (S), evapotranspiration values (ET), and the measurements for plant width, height, diameter, root length, number of leaves, titratable acid content, and dry matter amounts are provided in Table 1. As indicated by the table and according to the ANOVA test conducted across all irrigation subjects, no statistically significant differences were observed. However, upon examining the quantities of irrigation water, the lowest amount was recorded for the evening irrigation at 21:00 (S21.00), followed by the morning irrigation at 07:00 (S07.00) and then the noon irrigation at 12:00 (S12.00). When considering the physical development of the lettuce plant in relation to the amounts of irrigation water applied, the highest values in terms of width, length, and diameter were observed in the morning irrigation (S07.00). This suggests that plants utilize solar energy most efficiently after morning watering by combining the moisture and nutrients applied with the increasing solar radiation post-morning. The morning irrigation (S07.00) was followed by the evening irrigation (S21.00), where the measurements for width, height, and diameter were higher compared to those during the noon irrigation (S12.00). The lowest values were recorded during the noon irrigation (S12.00), presumably because the rate of evaporation within the plant water consumption is significantly higher at this time due to peak solar radiation, and the transpiration rate is also lower compared to other times of the day. The longest root length was achieved during the noon irrigation (S12.00), which coincides with the lowest above-ground plant measurements, suggesting that the plant more effectively utilizes the applied irrigation water and solar radiation for root development during noon. This is followed by morning (S07.00) and evening (S21.00) irrigations. Despite changes in irrigation times, the leaf number was 36 in the morning, 34 at noon, and 35 in the evening. Titratable acid content (TETA) was 0.4 in the morning, 0.3 at noon, and 0.3 in the evening. The dry matter (DM) content was 3.2 in the morning, 3.2 at noon, and 3.3 in the evening. These results show no significant differences in the averages of leaf number, TETA, and DM, indicating similar results across these parameters and suggesting that the time of irrigation (morning, noon, or evening) does not significantly affect these three parameters.

Table 1. Applied irrigation water, plant water consumption and plant physical and chemical properties.

Dates	Irrigation Topics	Irrigation Water (g)	Irrigation Water	ET (g)	ET (mm)	Width (cm)	Length (cm)	Diameter (cm)	Root length (cm)	Leaf number	TETA (%)	DM (%)
14.12.2023*	$S_{07.00}$	3680	130	3700	131	27.2	19.7	30.8	26.8	36	0.4	3.2
	$S_{12.00}$	3694	131	3783	134	23.7	17.7	25.7	30.8	34	0.3	3.2
	$S_{21.00}$	3379	119	3399	120	24.7	18.0	28.7	23.5	35	0.3	3.3

*According to the Anova test results in all subjects, the difference between the groups is due to chance.

The yield obtained from the trial (in grams per plant), along with the fresh weight of leaves, dry weight of leaves, and fresh and dry weights of roots, are provided in Table 2. The quantities of irrigation water applied varied according to the irrigation subjects, but the yield and quality parameters did not show significant differences according to the results of the two-way ANOVA test, indicating that the differences among subjects could be attributed to chance. As of the last harvest on December 14, 2023, a single plant's fresh weight for the morning irrigation subject (S07.00), corresponding to 130 mm of irrigation water, was 278.3 g. For the noon irrigation subject (S12.00), with 131 mm of irrigation water, it was 236.3 g, and for the evening irrigation subject (S21.00), with 119 mm of irrigation water, it was 232.7 g. Despite the highest amount of irrigation water being applied at noon, the highest yield per plant was obtained from the morning irrigation. This was followed by the yields of noon and evening irrigations, respectively. The largest leaf area and root weight were achieved in the morning irrigation. These results indicate that morning irrigation is more effective in terms of yield and plant growth compared to the irrigations applied at noon at 12:00 and in the evening at 21:00. Noon irrigation was shown to be more disadvantageous compared to both morning and evening irrigations. However, while the above-ground development was lower during noon irrigation, root development was greater than that observed in the morning and evening irrigations.

Table 2. Effect of different irrigation applications on lettuce leaf and root development

Dates	Irrigation Topics	Leaf Fresh Weight(g)	Leaf Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Leaf Area (cm2)
06.10.2023	$S_{07.00}$	0.4	-	0.6	-	13.02
	$S_{12.00}$	0.4	-	0.6	-	13.02
	$S_{21.00}$	0.4	-	0.6	-	13.02
01.11.2023	$S_{07.00}$	20	1	5	0.9	615.3
	$S_{12.00}$	13	0.5	7	0.7	376.4
	$S_{21.00}$	9	1.3	3	1.2	340
30.11.2023	$S_{07.00}$	205	8.9	47.7	10.8	2892
	$S_{12.00}$	186.3	8.93	40	7.5	2868
	$S_{21.00}$	229.3	11.3	50	11.2	3405
14.12.2023*	$S_{07.00}$	278.3	10.2	79.7	11.5	3863.4
	$S_{12.00}$	236.3	9.8	69	6.8	3405.2
	$S_{21.00}$	232.7	11.2	70.7	11.2	3455.8

*According to the Anova test results in all subjects, the difference between the groups is due to chance.

Conclusion And Evaluation

In this study, the quantity of irrigation water applied based on the mini evaporation pan with an automated irrigation system was found to be lower compared to previous systems that were manually controlled. The automation of irrigation water control allowed for a more efficient application in the plant root zone, resulting in more effective utilization of plant nutrients. In lettuce cultivation, applying irrigation water in the morning hours enabled the plant to more effectively use both the irrigation water and the nutrients carried by it, amplified by the solar radiation after the morning hours. This was clearly demonstrated through parameters such as plant width, height, diameter, and leaf area, and was also reflected in the yield values. Although there wasn't a significant difference in yield between the noon and evening irrigations, the evening irrigation at 21:00 was found to be more advantageous than the noon irrigation at 12:00 due to the lesser amount of irrigation water applied. Despite the highest amount of irrigation water being applied during the noon irrigation, it did not yield the highest values in terms of productivity. Therefore, for the most effective use of irrigation water and to achieve a higher quality product, morning irrigations should be preferred if possible.

Acknowledgements: The authors would like to thank the Scientific and Technical Research Council of Turkey (TUBİTAK). Under the scope of the “2209- University Student Research Project Support Program”, Reference No. 1919B012300502, has been supported by TUBITAK.

Researchers' Contribution Rate Declaration Summary

The authors declare that they have contributed equally to the article.

Conflict to Interest Declaration

The authors declare that there is no conflict of interest between them.

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