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Enhancing melon yield through a low-cost drip irrigation control system with time and soil sensor

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Abstract: Drip irrigation is a highly efficient method for watering crops, as it delivers water directly to the roots and minimises wastage due to evaporation or runoff. This paper presents the development and implementation of a low-cost drip irrigation control system that uses both time- and soil sensor-based approaches. The system's efficiency was compared through a field experiment of melon growing, divided into three categories and four replications using a completely randomised design. The treatments include: *T*1 [time-based irrigation (TBI)], *T*2 [soil moisture-based irrigation (SMI)], and *T*3 [hand watering irrigation system (HWI)]. Results indicated that the TBI technique resulted in faster plant growth compared to the other treatments, as evidenced by increased leaf widths, lengths, numbers, and stem diameter. All irrigation techniques showed significant differences in yield characteristics, with TBI and SMI producing no differences in the first flowering day of female fruit widths, lengths, and weight of melon. However, the HWI treatment resulted in lower fruit length and weight yields. Cost analysis showed that the system is beneficial as a very low-cost device that is affordable, precise, and useful for measuring and controlling irrigation-related parameters for melon cultivation.

Keywords: Arduino; field experiment; irrigation automation; melon cultivation; yield characteristics

Melon (*Cucumis melo L.*) is a major global horticulture crop with a total annual melon production of 30 million t worldwide (Zhang et al. 2019). Melon is a fast-growing plant that produces a big quantity of fruits. It is varied, trailing, and softly hairy, and the weather and growing conditions of the plant mostly influence its growth. Among the types, round fruits are the most prevalent.

With regard to the production of melons, water may be considered to be a key component in assuring a high yield of melons. According to some studies, melon is susceptible to water deficiency, which might result in decreased fruit yield and quality. In addition, excessive soil moisture can harm melon and produce poor fruit quality (Sensoy et al. 2007). Sensoy et al. (2017) stated that melon roots require soil water to be maintained at a minimum of 65% of field capacity to avoid a water deficit. Evapotranspiration rises as the plant grows, resulting in excessive moisture or water stress, which can result in decreased yield, low quality, and plant disease (Nut 2019).

From previous research, it can be seen that water plays an important role in melon production. However, in traditional cultivation, the melon's production and quality characteristics are highly unpredictable. Due to the ineffective water management capabilities of traditional methods and sprinkler irrigation, it is difficult to produce improved water-saving and production-increasing benefits. As a result, conducting experiments on acceptable

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melon irrigation techniques and studying the impacts of various alternative water-saving irrigation methods on melon development can lead to ensuring a high yield of melons.

Drip irrigation is a relatively recent watering technique for melon production that maintains the soil's root zone at a constant moisture level (Jusoh et al. 2020). A simple drip irrigation system provides the plant with water and nutrients directly by drip-feeding water to the root zone. Because of the low flow rate and low pressure, the emitters on the drip irrigation system get a small amount of water. This irrigation method reduces water loss due to evaporation from wind and surface runoff (Pramanik et al. 2016). Likewise, this has asserted the efficacy of drip irrigation in providing an effective irrigation system by providing the appropriate amount of nutrients to the plants to minimise nutrient leaching (Elasbah et al. 2019).

In terms of control techniques for precision irrigation, these may be classified largely into closed-loop and open-loop control schemes. Similarly, a hybrid control technique has been developed combining closed-loop and open-loop control methods (Abioye et al. 2020). In an open-loop irrigation control system, the operator empirically makes irrigation decisions based on mechanical or electromechanical irrigation timers and the amount of water supplied. Water amount and time of irrigation are typically determined and given primarily on the operator's estimate of crop response, rather than on precise measurements. An open-loop system is simple to construct since no sensors are necessary to monitor the environmental changes influencing the plant, and there is also no requirement for a feedback concept, which reduces the cost (Sudarmaji et al. 2019). In the case of closed-loop irrigation, the controllers use a feedback control technique to maintain the optimal output state by comparing it to certain pre-set conditions in order to determine the duration and amount of water supplied to the plants. There have been a large number of research publications on monitoring and autonomous irrigation connected with the Internet of Things system (Navarro-Hellín et al. 2015; Kodali and Sarjerao 2017; Abba et al. 2019; Nawandar and Satpute 2019; Borah et al. 2020; Hamdi et al. 2021;). Their method relied on a closed-loop control technique, in which soil, plant, and weather factors were integrated to determine the crop's water requirement, as well as to schedule and optimise irrigation. The closed-loop control method may be divided into several types of control systems, including linear control, intelligent control, optimal/adaptive control, and others (Abioye et al. 2020).

From technological advancements, there has been a significant growth in the number of automated irrigation water management systems. However, the high cost of these cutting-edge devices is a considerable constraint for farmers and researchers. Additionally, the majority of commercial irrigation systems on the market are specially designed, making them difficult to adjust and control adaptively (Abioye et al. 2020). As a result, the primary emphasis of this research was on low-cost management approaches for drip irrigation systems. Among the low-cost surface drip irrigation management approaches, there has been an interest in control systems for water conservation that are time-based and dependent on soil moisture levels. A time-based irrigation control system is an open loop approach that employs simple controllers comprised of clock units capable of activating one or more subunits of the irrigation system at a specified time (Sudarmaji et al. 2019). Additionally, a soil-based control system employs a low-cost soil moisture sensor, which is one of the most important criteria for an irrigation management system to be effective (Kothawade et al. 2016; Shigeta et al. 2018). So, the main contributions of this paper are as follows: The development of a low-cost drip irrigation control system that was both time-based and soil sensor-based and the implementation of the system through plastic roof net-house melon growing to compare the efficiency of growth and yield in a field experiment.

MATERIAL AND METHODS

System design

Low-cost drip irrigation systems. The block diagram of the system architecture and a prototype of a low-cost drip irrigation control system were developed, as shown in Figures 1 and 2, respectively. The system will be managed and controlled in accordance with the design, which will support both time-based and soil sensor-based control systems. Such a system was designed based on a modular structure that consists of numerous electronics interconnected boards:

The main-board. This is an electronic board, which has already been used to control the system. The following equipment was utilised in this project: The Arduino Mega 2560 is utilised as the main con-

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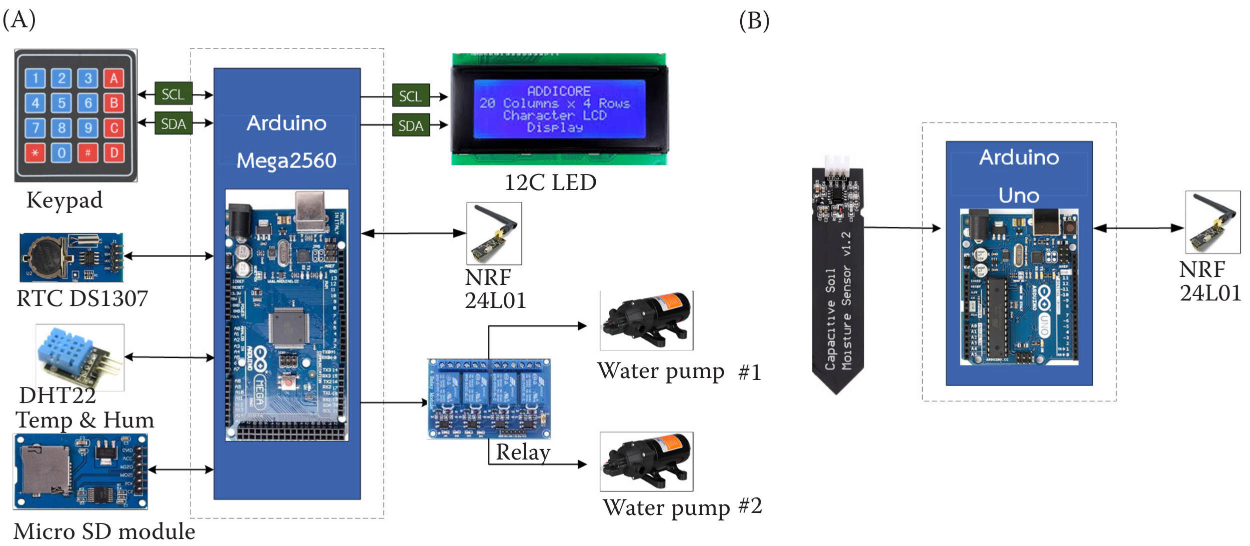

Figure 1. Overall system architecture block diagram: (A) mainboard unit and (B) sensor-board unit
RTC – real-time clock; NRF – nordic radio frequency; DHT – digital humidity and temperature

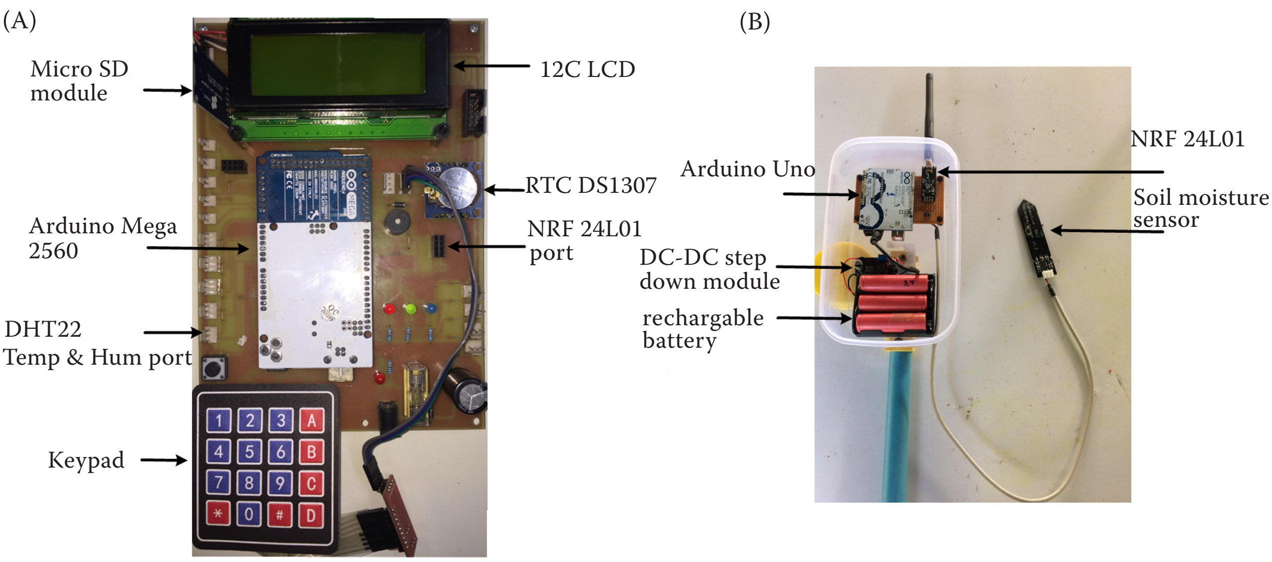

Figure 2. A low-cost drip irrigation system prototype: (A) mainboard unit and (B) sensor-board unit
RTC – real-time clock; NRF – nordic radio frequency; DHT – digital humidity and temperature

troller, and it is responsible for processing all of the data collected from various sensors. The DS1307 serial real-time clock (RTC) provides timekeeping features for use in a time-based system. The I2C LCD displays the temperature, humidity, date and time. A keypad for configuring the temperature, humidity, date and time. The DHT22 sensor monitors the temperature of the interior of the house. The relay is used to control an electrical circuit by acting as a switch. A water pump is utilised to supply water to the melon. A Micro SD is used to store the data from the sensor reading and the measurement time.

The sensor-board. This provides the interface with the connected sensors. The following equipment was utilised in this project: The Arduino Uno board is utilised to control the sensor-board and receive soil moisture data. The NRF 24L01 module (Nordic Semiconductor, Norway) is used to establish a wireless connection between the sensor-board and the main system.

Software system. As seen in Figure 3, the software is designed to support both time-based and soil-sensor-based irrigation systems. At program start-up, the software will read the configuration value from

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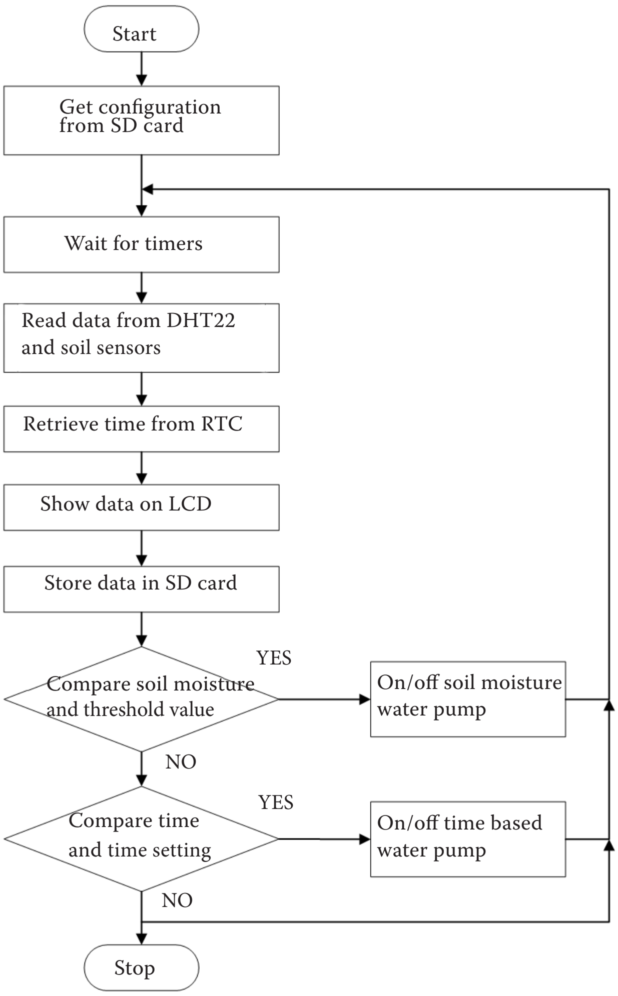

Figure 3. Flowchart of main-board programming

the SD card, which will keep the default settings for both irrigation techniques. The system will read the temperature and soil moisture of the inside of the home at the timer intervals (every 1 sec), retrieve the time from the RTC, show the data on the LCD, and save the data to the SD memory.

For the time-based irrigation system, this was performed by scheduling time from a keypad and comparing it to a real-time clock using an Arduino board attached to a relay for switching the water pump. Concerning soil sensor-based irrigation, the automatic control system is determined by the set point value of the field's groundwater content. Calibrations can be made through trial-and-error approaches. A moisture threshold value is set for enabling water to flow based on the soil moisture sensor data. When the soil moisture condition is below or above the threshold value, the microcontroller will send a signal to the relay to turn on or off the water pump.

Experimental design and treatments

The experiment was conducted at the Creating Innovation for Sustainable Development Research Center (CISD-RC), Nakhorn Pathom Rajabhat University, Thailand (13°51'41.6" N; 99°59'49.6" E) during the growing seasons 2020/2021. The tested variety was 'Thunder gold 1497', the melon seed from Chia Tai Company, Thailand. This has orange flesh and round fruit with a silky yellow skin. It is ready to harvest 70–75 days after germination. The experiment was designed as a completely randomised design (CRD) and was divided into three categories with four replications, with each iteration randomly gathering five plants. The experiment included the following treatments: *T*1 [time-based irrigation (TBI)], *T*2 [soil moisture-based irrigation (SMI)], and *T*3 [hand watering irrigation system (HWI)].

First, soak melon seeds in water for 3–6 h to enhance melon germination. Then, melon seeds are incubated for 24 to 48 h in cloth-wrapped trays. Then, melon seeds were planted in seedling trays using a 2 : 1 mixture of coconut coir and peat moss and watered properly once a day. After 14 days of germination, the uniform-sized melon was transplanted into the plastic roof net-house treatment setting to protect the plant from heavy rain and high relative humidity. The layout of the melon plot can be illustrated in Figure 4. According to the figure, each treatment comprised 50 plants in two rows. The size of the experimental plots was 16 m long and 1.2 m wide and raised 15 cm above the ground, with a 60 cm spacing between each plant.

Prior to transplanting, soil preparation was performed using a 1 : 2 mixture of soil and chopped coconut husks as planting material. This indicates that the soil used may be heavy in clay, and the addition of coconut husks is intended to improve drainage. Therefore, it's possible that the soil type is loamy.

In order to fertilise the plants, a compound fertiliser with the ratio of NPK 15 : 15 : 15 was applied at a rate of 10 grams to each plant on a weekly basis. After 60–65 days had passed since the melon seed was germinated, 15 grams of a fertiliser mixture consisting of NPK 15 : 15 : 15 and NPK 0 : 0 : 60 were applied to the plant. All other features of field management, including as fertilisation, weeding, spraying, and pruning, were carried out in the same manner.

Irrigation was conducted according to various treatments adjusted to the crop growth stage and environmental circumstances. In this paper, the experimental design categorised melon growth into

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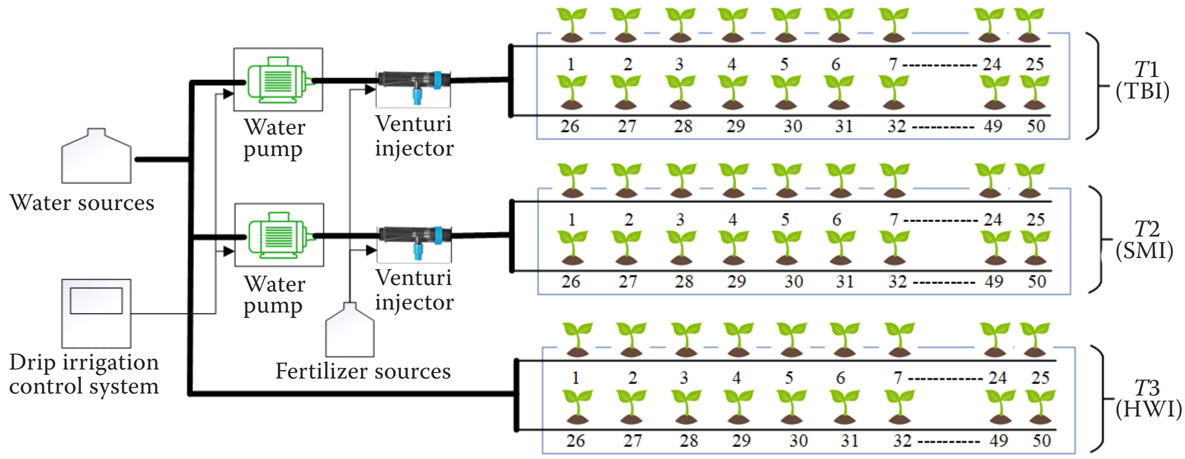

Figure 4. Setup of experimental plot
TBI – time-based irrigation; SMI – soil moisture-based irrigation; HWI – hand watering irrigation system

four stages: seeding, flowering and fruiting, expansion, and maturity.

The provided data suggests that Chaoumeadand et al. (2019) conducted a study on melon cultivation in a greenhouse using environmental control methods such as temperature, air humidity, and soil water. However, given the lack of information on the application of drip irrigation in tropical environments, it is important to investigate the potential impact of manual irrigation and control measures. Standardised methods for manual irrigation and control measures are crucial in any field experiment to ensure accurate and reproducible results. Without clear information on water dosage and control measures, comparing results between studies and drawing meaningful conclusions about the effectiveness of different irrigation methods may be challenging. In this context, the study employed the soil moisture control level to determine the relationship between melon growth and the amount of water required per day (Table 1) based on the work of Chaoumeadand et al. (2019). The treatment period began with the flowering and fruit setting stage and finished with the maturity stage between September 28 and November 2, 2020.

System implementation and data collecting

A prototype of low-cost drip irrigation systems was assembled in control cabinet and installed in the plastic roof net-house condition size of 6 × 20 m. The drip irrigation system was set up with two 12 VDC high-pressure micro diaphragm water pumps. These pumps used water and fertiliser from the water and fertiliser tank to get to the field (*T*1 and *T*2). Each

Table 1. A relationship between melon growth and the amount of water required per day

Crop stage	Date	Week	Amount of irrigation (L/plant/day)	Soil moisture (%)
Seeding stage	September 14	1	–	–
	September 21	2	–	–
Flowering and fruit setting state	September 28	3	1	30
	October 5	4	1	40
	October 12	5	2	60
	October 19	6	2	60
Expansion stage	October 26	7	3	80
	November 2	8	3	80
	November 9	9	3	80
	November 16	10	3	80
Maturity stage	November 2	11	–	–

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treatment was divided into two rows by connecting the main line [high density polyethylene HDPE)] directly to the lateral lines (the drip tape that was welded into the drip soaker tape every 20 cm), and the irrigation devices and the field pipe network were responsible for delivering water to each plot. The system was monitored with one soil moisture sensor for the *T*2 treatment. In terms of data collection, weekly trends in vegetative development parameters were identified, and plant samples were collected using a CRD design to determine the plant growth and yield of Thunder gold 1497 melon under different treatments. The statistical analysis was processed by one-way analysis of variance (ANOVA) by using SPSS software (version 22).

RESULTS AND DISCUSSION

Effects of different irrigation methods on the growth and yield. The crop stage of melon under plastic roof net-house can be shown in Figure 5. For the results of melon's development that were observed after transplanting, plant samples were chosen at random from each treatment and measured every seven days until 28 days. Leaf widths, leaf lengths, stem diameters, and leaf numbers were measured on a regular basis at the fourth harvesting phases (7, 14, 21 and 28 DAT) during the plant growth stage, as shown in the results and Table 2. The results indicated that time-based drip irrigation on plant development grew faster than other treatments in terms of leaf widths, leaf lengths, and leaf numbers. In a similar manner, this technique could be used to obtain a larger stem diameter.

As for the effects of the treatments on the yield of Thunder gold 1497 melon, the results (Table 3) showed that all irrigations had significant differences in yield characteristics. TBI and SMI were not difference in terms of first flowering day of female, fruit widths, fruit lengths, and weight of melon. However, irrigation by HWI treatment resulted in a lower yield of fruit length and weight than TBI and SMI drip irrigation.

In order to determine the quality of the melon, we randomly select five maturity-stage melons (one fruit per replication). Many criteria, including soluble solids (SS), the melon peel and pulp colour, and firmness, were determined after the maturity stage was completed. With the use of a hand refractometer (Atago) and the approved technique AOAC 932.12 (2000) for titratable acidity, the specific gravity was calculated based on the melon juice extraction (AOAC 2000). A Minolta colour meter (Konica Minolta, Japan) was used to provide an accurate reading of the colour of the melon peel and pulp (Model CR-200). The firmness of the fruit was measured with an Effegi firmness meter (FT011, Effegi, Italy). the results were that: Soluble solid was 13.0 ± 0.41° Brix, titratable acidity was 0.15 ± 0.02%, and firmness was 22.0 ± 2.16 N.

In discussion, there are research papers on the effects of irrigation on melon growth, yield, and quality. One such paper by Zhang et al. (2018) investigated the effects of different irrigation strategies

(A) (B) (C) (D)

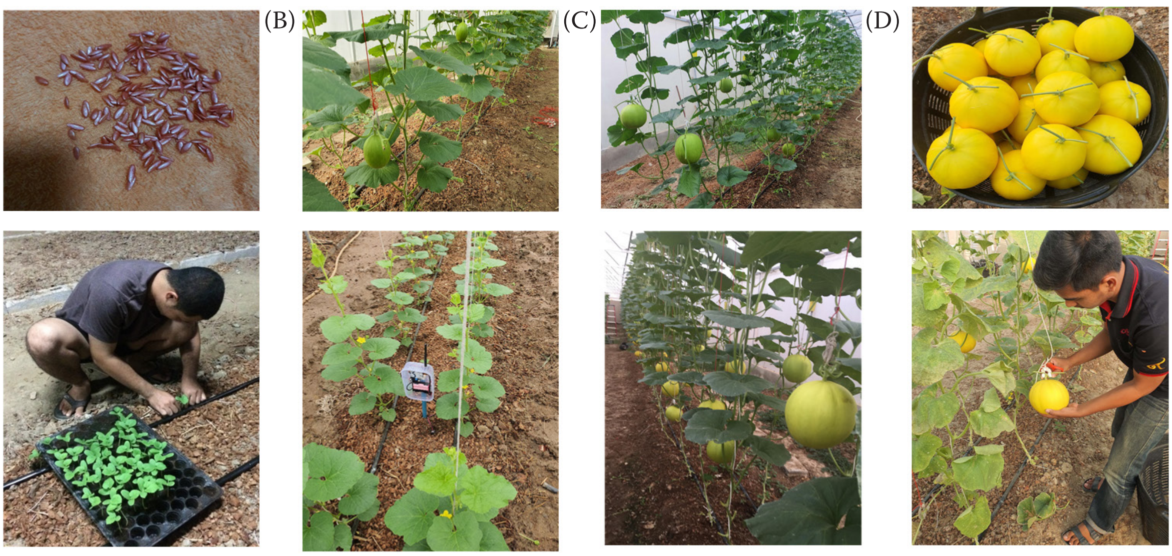

Figure 5. Crop stage of melon 'Thunder gold 1497': (A) seeding stage, (B) flowering and fruit setting state, (C) expansion stage and (D) maturity stage

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Table 2. Mean parameters of 7, 14, 21, and 28 days after planting of Thunder gold 1497 melon under different treatments

Parameters	Day	Treatment (average ± SD)		
		*T*1 (TBI)	*T*2 (SMI)	*T*3 (HWI)
Leaf widths (cm)	7	7.07 ± 0.58	6.39 ± 0.99	4.91 ± 0.70
	14	14.45 ± 0.86	11.94 ± 0.45	10.37 ± 0.83
	21	17.45 ± 0.86	14.38 ± 0.57	14.05 ± 0.67
	28	19.39 ± 0.94	16.45 ± 0.84	15.58 ± 0.99
Leaf lengths (cm)	7	6.56 ± 0.84	5.22 ± 1.04	4.06 ± 0.91
	14	10.34 ± 0.87	8.49 ± 0.85	7.40 ± 0.96
	21	12.50 ± 1.04	10.46 ± 1.02	9.32 ± 0.78
	28	12.90 ± 0.88	11.14 ± 0.89	10.52 ± 0.86
Stem diameters (mm)	7	4.18 ± 0.96	3.66 ± 0.75	3.06 ± 0.88
	14	5.60 ± 0.88	5.40 ± 0.80	4.05 ± 1.02
	21	6.52 ± 0.94	5.87 ± 0.97	5.37 ± 0.85
	28	9.95 ± 0.84	9.06 ± 0.89	8.71 ± 0.79
Leaf numbers (leaf)	7	5.49 ± 0.91	5.71 ± 0.68	4.86 ± 0.82
	14	9.31 ± 0.86	9.31 ± 0.86	7.20 ± 1.05
	21	15.46 ± 0.82	14.11 ± 0.82	14.08 ± 0.96
	28	25.97 ± 0.91	22.29 ± 0.93	20.96 ± 1.03

TBI – time-based irrigation; SMI – soil moisture-based irrigation; HWI – hand watering irrigation system; SD – standard deviation

Table 3. Some parameters of the yield of Thunder gold 1497 melon under different treatments

Parameters	Treatments		
	*T*1 (TBI)	*T*2 (SMI)	*T*3 (HWI)
First flowering of male (DAT)	21.44 ± 0.812^{a}	22.30 ± 0.71^{b}	24.58 ± 0.73^{c}
First flowering of female (DAT)	10.39 ± 0.76^{a}	10.52 ± 0.78^{a}	12.38 ± 0.67^{b}
Fruit widths (cm)	12.98 ± 0.73^{a}	12.72 ± 0.70^{ab}	12.37 ± 0.71^{b}
Fruit lengths (cm)	10.43 ± 0.80^{a}	10.30 ± 0.84^{a}	9.75 ± 0.68^{b}
Weight (kg)	2.24 ± 0.22^{a}	2.24 ± 0.27^{a}	1.89 ± 0.29^{b}

^{a,b,c} Significant difference at level $P < 0.05$ by DMRT (Duncan Multiple Range Test); the values are means ± standard deviation of twenty separate measurements; TBI – time-based irrigation; SMI – soil moisture-based irrigation; HWI – hand watering irrigation system

on the yield, quality, and water use efficiency (WUE) of melon under plastic mulch. The treatments included surface drip irrigation (SDI), subsurface drip irrigation (SSDI), and plastic mulch with drip irrigation (PMDI). The results showed that PMDI had the highest yield and WUE, followed by SSDI and SDI. In terms of quality, PMDI and SSDI had higher soluble solids content, total sugar content, and vitamin C content than SDI. Similarly, the results presented in the given data also show that the TBI and the SMI resulted in better yields and quality of melon compared to HWI. The results also indicate that TBI was not significantly different from SMI in terms of yield and quality parameters. The given data and the research paper by Zhang et al. (2018) suggest that different drip irrigation strategies can be adopted based on factors such as crop type, soil type, and climate conditions to optimise water use efficiency and maximise crop productivity.

Other articles related to melon production and irrigation, one such article by Khani et al. (2020). In this study, the authors investigated the effects of different irrigation schedules (irrigation every 2, 4, or 6 days) and mulching on melon's yield, quality, and water use efficiency. The results showed that the melon plants irrigated every 4 days with mulch had the highest yield and quality, as well as the highest water use efficiency. These findings suggest that proper irrigation scheduling can have a significant impact on melon production. By optimising irriga-

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Table 4. The total cost of developing hardware

Circuit description	Component description	Unit	Unit price (USD)	Amount (USD)
Main-board	microcontroller Arduino Mega 2560 board	1	13.00	13.00
	RTC DS1307	1	0.70	0.70
	I2C LCD 20 x 4	1	6.66	6.66
	I2C Keypad 4 × 4 (PCF8574)	1	1.06	1.06
	temperature humidity sensor DHT22	1	4.00	4.00
	micro SD card reader module (Catalex)	1	1.17	1.17
	transceiver module NRF 24L01	1	2.37	2.37
	relay module 4 channel	1	2.33	2.33
	power adaptor AC 220V to DC 5V 2A	1	2.33	2.33
	circuit breaker NF30CS 2P 15 A	1	11.67	11.67
	water pump (SEAFLO-21)	2	20.00	40.00
	control cabinet 300 × 450 × 150 mm.	1	20.00	20.00
	miscellaneous (resistors, capacitors, terminal block, single layer PCB)	–	16.67	16.67
Sensor-board	microcontroller Arduino Uno board	1	5.63	5.63
	transceiver module NRF 24L01	1	2.37	2.37
	capacitive Soil moisture sensor 1.2	1	2.67	2.67
	DC-DC step-down module LM2596S	1	1.00	1.00
	battery Li-ion 3.7 VDC 9 900 mAh, li-ion 18650	3	3.53	10.59
	miscellaneous (resistors, capacitors, terminal block, enclosure box)	–	10.00	10.00
Total amount				154.22

RTC – real-time clock; NRF – nordic radio frequency; PCB – printed circuit board

tion practices, farmers can increase yields and improve the quality of their crops, while also conserving water resources.

Cost analysis. The total cost of developing the circuit and hardware is listed in Table 4. Cost patterns are subject to vary over time as a result of currency exchange rate movements on the global market. Cost analysis does not include shipping, value-added tax, or labour. As can be seen, the total cost of the complete prototype is USD 1 54.22, indicating a very low-cost device that is affordable and very useful for measuring and controlling irrigation-related parameters in comparison to the approaches presented by others.

CONCLUSION

This work focuses on the growth and development of melon plants under different irrigation techniques, as well as the quality of the resulting melons. On the other hand, the current data focuses on the cost of developing a circuit and hardware for measuring and controlling irrigation-related parameters. Both parts have important implications for agriculture and farming. The first data highlights the importance of selecting appropriate irrigation techniques to promote plant growth and optimise crop yield. The results suggest that time-based drip irrigation may be a more effective approach for promoting the growth of melon plants compared to other techniques. The second set is relevant because it addresses the issue of affordability in relation to agricultural technology. The low cost of the irrigation device suggests that it could be a practical solution for farmers with limited resources who want to optimise their crop yield through efficient irrigation. Taken together, this work highlights the importance of both optimising agricultural practices and ensuring that the technology used in agriculture is affordable and accessible. By incorporating both approaches, farmers can work to increase their crop yields while minimising their costs and improving their overall economic viability.

However, based on previous research, another factor other than irrigation systems may be responsible for differences in cultivated plants. The study

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by Sharma et al (2014) investigated the effect of two irrigation rates (100 and 50% crop evapotranspiration) on the root growth, yield, and fruit quality of three melon cultivars (Mission, Da Vinci, and Super Nectar) in semi-arid conditions. The results showed that deficit irrigation (50% ETc) had different effects on root growth depending on the cultivar. However, deficit irrigation caused a significant reduction in marketable yield by 30% in both seasons due to a decrease in fruit size. The reduction in yield varied with the cultivar, but there was no adverse impact on melon fruit quality. Another aspect proposed by Visconti et al. (2019) is that this study compared the effects of three irrigation systems – drip, subsurface drip, and flood - on soil salinity, yield, and quality of melons. The results showed that while flood irrigation maintained lower soil salt levels than the other two systems, drip and subsurface drip irrigation provided higher and more consistent soil moisture, resulting in higher total and marketable yield and fewer damaged melons. The results suggest that the modernization of traditional irrigation systems in moderately salt-affected lands through the implementation of drip and subsurface drip irrigation systems could enhance melon crop productivity and quality.

Future work is to assess the long-term effects of the different irrigation systems on soil health and sustainability. This could involve monitoring changes in soil organic matter, nutrient levels, and microbial activity over time. Additionally, it may be valuable to investigate the impact of the different irrigation systems on other crops grown in rotation with melons and on overall farm profitability. Finally, there may be opportunities to refine and improve the irrigation measurement and control device developed in this study. This could focus on integrating the device with a smartphone application to provide farmers with real-time data on soil moisture and other irrigation-related parameters. Additionally, further testing and validation of the device could help to optimize its accuracy and reliability in a range of agricultural settings.

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