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Development of a low-cost weather station and real-time monitoring for automated irrigation management

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ABSTRACT. Irrigation is a practice that increases productivity and enables the expansion of agricultural borders. This practice should be well managed to ensure the efficient use of water by plants, and such management requires specialized labor, which increases operating costs. Therefore, the main objective of this study is the implementation of an automated irrigation system that considers factors ranging from water demand to the operation of the system. Because the daily water demand is determined by crop evapotranspiration, a low-cost weather station was developed to acquire data daily. Such data can be used to estimate the reference evapotranspiration (ET_0) using the Penman-Monteith model of the Food and Agriculture Organization (FAO). Thus, by combining the amount of water required by a crop with the physical and hydraulic properties of the soil and the hydraulic properties of the irrigation system, it was possible to determine the daily frequency and amount of time required for the system to operate to meet the water requirements of the crop without undergoing stress from a deficit or an excess of water. The management/monitoring system was designed and implemented to allow the user to access data remotely through an online application. This application enables the real-time transmission of irrigation-related data, such as weather station data and system logs, obviating the need for the user to be present at the crop site. This allows the supervision of many areas simultaneously with low cost.

Keywords: Irrigation; automation; evapotranspiration; drip; weather station; AWS

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Introduction

Agriculture consumes approximately 70% of all freshwater on the planet and is the socioeconomic activity that uses the most water in the world. This number can exceed 80% in some underdeveloped countries. In additionto being the most water-consuming activity, agriculture is also the most water-wasting one. According to data from the Food and Agriculture Organization of the United Nations (FAO), almost half of all the water used in the field is wasted, and the volume of water saved by rural areas decreasing their water consumption by 10% would be sufficient to supply the world population twice (Pena, 2017).

Currently, in Brazil, just over 8% of the planted area is irrigated; however, this area accounts for approximately 16% of the food produced and 35% of the agricultural production value. It is noteworthy that agribusiness accounts for approximately 22.15% of the Brazilian GDP, generating close to 37% of all jobs in the country and representing approximately 39% of exports (Ecoagro, 2012). In this sense, Rodrigues, Domingues, and Christofidis (2017) noted the importance of irrigated agriculture and the increasing necessity of technological improvements. Despite the modernization of agriculture in recent years, many farms, mostly small and medium-sized ones, still employ manual irrigation because automated systems typically involve high installation and maintenance costs, making it difficult for small and medium-sized producers to use them.

Grah et al. (2012) conducted an assessment of irrigation systems and concluded that automated systems were better than conventional methods because they save water and increase crop yields. The authors were also concerned with the lack of electricity in some regions and thus developed an autonomous irrigation system that uses hydraulic-mechanical power as an alternative irrigation pumping system for places lacking electricity.

In addition to irrigation efficiency, some systems consider convenience so that the user does not have to be on-site to monitor the irrigation process. For these systems, the user is able to manage/control the system and receive feedback online and can thus access it from anywhere in the world (Nagarajan & Minu, 2018;

Montoya, Obando, Morales, & Vargas, 2017; Rajalakshmi & Mahalakshmi, 2016; Hamouda & Elhabil, 2017; Isık, Sonmez, Yılmaz, Ozdemir, & Yılmaz, 2017; González-Esquiva et al., 2017; Masseroni et al., 2017; Mohandas, Sangaiah, Abraham, & Anni, 2017).

An irrigation system can be classified as automated when it decides when and how much to irrigate or manage. In the case of automated management, information is passed on to the user, who decides what to do with the data and when to irrigate. However, some systems have both characteristics; the entire system can be autonomously managed, but the user can influence and control the system's decisions (Rajalakshmi & Mahalakshmi, 2016; Hamouda & Elhabil, 2017; Qi, Lu, & Dai, 2017; Savic & Radonjic, 2016).

Solutions for automating irrigation must also be affordable. Gervásio and Melo (2014) proposed a lysimeter to accurately measure the water consumption of plants grown in containers and were able to achieve a cost reduction compared to commercial systems.

Susmitha, Alakananda, Apoorva, and Ramesh (2017) and Sirohi, Tanwar, Himanshu, and Jindal (2016) improved irrigation water use using weather forecasts. Olszewski, Jeranyama, Kennedy, and DeMoranville (2017) focused on using automated irrigation in periods of frost to prevent plants from freezing and to reduce soil saturation.

Irrigation automation is not exclusive to the rural sector. Studies have shown the need to improve the efficiency of urban lawn irrigation to save water, and successful strategies have been developed (Blado et al., 2017; Koprda, Magdin, Vanek, & Balogh, 2017). Asadullah and Ullah (2017) developed a low-cost and efficient design for indoor plant irrigation that reduces human labor and saves energy.

In this sense, the main objective of this paper was to develop and evaluate low-cost equipment aiming at the automated management of a localized irrigation system. For this purpose, specific objectives were established, such as the construction and calibration of an automatic meteorological monitoring system for the purpose of determining reference evapotranspiration, the development of an algorithm for the calculation of crop evapotranspiration, gross irrigation depth, time of irrigation and the construction of an interface for the integration of monitoring and control systems with the user allowing monitoring and intervention.

Material and methods

An automatic weather station (AWS) was developed in this study in threestages: development, calibration, and data comparison.

The development of the irrigation control system was divided into two stages: development and irrigation system simulation tests.

The development of the application was divided into two stages: development and systems integration.

The calibration of the sensors and a comparison of the data were performed at the National Institute of Meteorology (INMET) Conventional Station, located in Lavras, Minas Gerais State, Brazil at 21° 14' South, 45° 00' West and an altitude of 918.8 m and registered by the World Meteorological Organization (WMO) under code 83687. The tests were performed through simulations, considering an area of 250 square meters (25 m x 10 m).

Development of the automatic weather station

The AWS is divided into three parts that automatically read and record the meteorological variables, and the data records are stored in the external memory of the equipment and saved to the cloud. The application provides access to data from the previous year in monthly, daily, or hourly intervals or on a real-time basis.

For the project design, a block diagram was prepared, as shown in Figure 1. The main block, named "Processing Center", manages all the functions of the equipment, including the system inputs and outputs. The blocks indicated by the arrows pointing toward the "Processing Center" block represent the input data and are labeled as "Power" and "Sensors". The "Power" block provides power for the system through a battery that is charged by a solar panel. The "Sensors" block is responsible for sending the electrical signals that represent the meteorological phenomena. The blocks indicated by the arrows pointing in both directions are input and output blocks and are labeled as "Clock", "Memory", and "Wi-Fi Data Transmission". The "Clock" block is responsible for informing the "Processing Center" block of the exact time to perform the operations. The "Memory" block stores the data collected by the "Sensors" block and processed by the "Processing Center" block. The "Wi- Fi Data Transmission" block sends the data collected by the "Sensors" block and processed by the "Processing Center" block to an online server, which receives the operations desired by the user to be handled by the “Processing Center” block. The “Actuators” output block is indicated by the arrow that is in the opposite direction to the “Processing Center” block and is responsible for the activation of the irrigation system sectors.

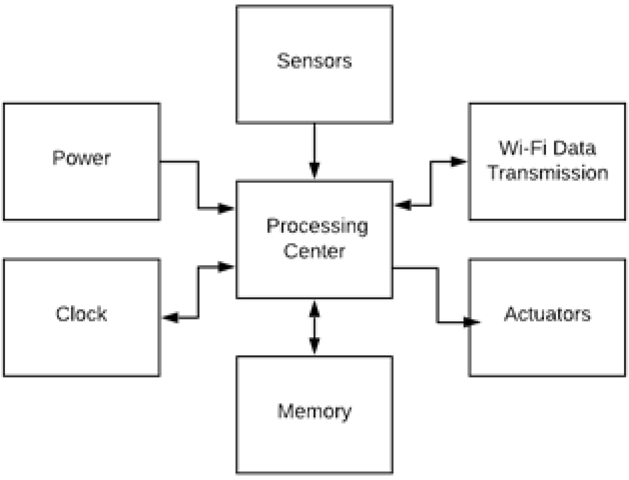

Figure 1. AWS block diagram developed.

Electronic circuit

The electronic circuit diagram is shown in Figure 2. An YwroBot adjustable power source is used to provide 3.3 V or 5 V to the modules and to prevent the Arduino board from being overloaded. The Arduino board is responsible only for signal readings through the input ports. The HDC1080 and BMP290 sensors and the RTC module are powered by 3.3 V, with their SCL (Serial Clock) and SDA (Data) ports connected to the SCL and SDA ports of the Arduino board, respectively. The BPW34 is powered by 5 V and connected to A0 with a 5.1 k resistor at the other output, which is connected to the ground. The reed switch has one output connected to the ground and one output connected to the D8. The micro SD card module was powered by 5v, MISO connected to D12, MOSI to D11, SCK to D12 and CS to D10. Lastly, the Ywrobot ground was connected to the Arduino ground to equalize the “ground” of both pieces of equipment.

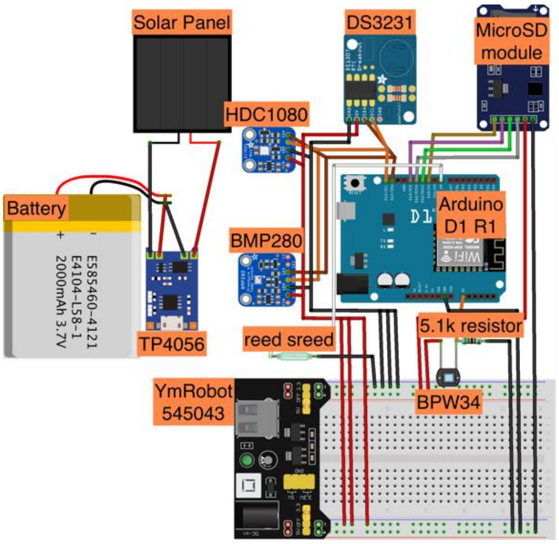

Figure 2. Components connection circuit.

Algorithm

The algorithm was developed based on the flowchart shown in Figure 3. The program starts by activating the sensors, following the standards established by their respective libraries. When the sensors are activated, a function is run to initialize the global variables necessary for the correct operation of the program as a whole. Then, a function is set to send the data collected by the system to the server every 2 seconds. All these instructions are executed in the Arduino setup. At the end of this step, the loop instructions are initialized. The first step is to perform the sensor readings iteratively and update the global variables. A log is generated for every hour of processing and contains the system records with information from the last hour of execution. After the log is recorded, the averages for the current day up until the execution time are calculated. Upon completion of the 24h period, the ET_c (crop evapotranspiration) was estimated by adjusting ET_0 (Equation 1 - standard global model for estimating reference crop evapotranspiration) with K_c (crop coefficent), (Allen, Pereira, Raes, & Smith, 1998). After that, the water content at field capacity and wilting point, the rooting depth and depletion fraction of the soil are input. So, the results are recorded in a file. At the end, the RAW (Readily available Soil Water in the root zone – Equation 2) is calculated to determine if a plant is experiencing or is close to experiencing water stress. If so, the system converts the necessary water depth to the time the system must remain running to meet the water needs of the plant without providing more water than the soil can contain. To ensure this behavior, the ET_c calculation is cumulative until it exceeds the remaining RAW. Thus, the irrigation schedule is not fixed and may vary according to the amount of water that is readily available to the plant throughout the day, depending on the ET_c.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

Where,
ET_0 – reference evapotranspiration, mm d^{-1};
R_n – daily radiation balance, $MJm^{-2}d^{-1}$;
G – total daily heat flow in the soil, $MJm^{-2}d^{-1}$;
T – average air temperature, °C;
u_2 – wind speed at a height of 2 m, m s^{-1};
e_s – vapor saturation pressure, kPa;
e_a – current vapor pressure, kPa;
e_s – e_a – vapor pressure deficit, kPa;
Δ - slope of the vapor pressure curve relative to temperature, kPa$°C^{-1}$;
γ – psychometric coefficient, kPa$°C^{-1}$.

$$TAW = 1000(\theta_{fc} - \theta_{wp})Z_r \tag{2}$$

Where,
TAW – total available soil water in the root zone, mm;
θ_{fc} – field capacity water content, m^3m^{-3};
θ_{wp} – water content at the wilting point, m^3m^{-3};
Z_r – effective root depth, m.

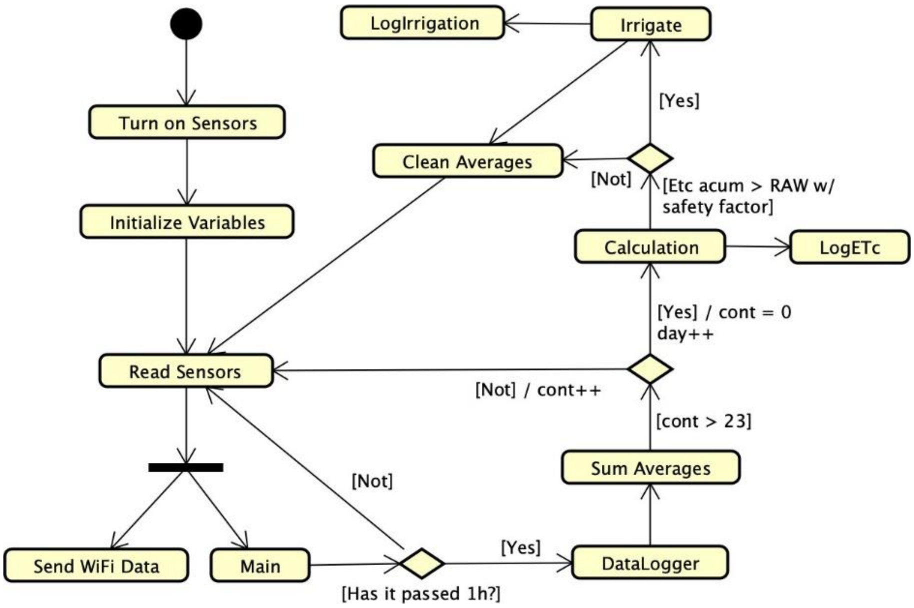

Figure 3. Algorithm flow chart.

Data for simulations

A drip irrigation system with four sections was considered to evaluate theresults of simulations. In addition, the result of Equation (3) was evaluated to determine if the value corresponding to the time the irrigation system remains running is ideal to meet the water needs of the plant. This water need is obtained by the water transfer from the soil-water-plant-atmosphere system and indicates the amount of water that must be replenished by the drip irrigation system, the flow rate of which is calculated in L h^{-1}. This equipment must drip long enough to provide the required amount of water without exceeding the field capacity. The simulation was carried out because the drippers were not installed due to cost reasons. Thus, the flow rate was considered to be the one specified by the manufacturer and was assumed to be real, regular and constant throughout the irrigation system.

$$T_i = \frac{L_b * E_g * E_L}{qe} \tag{3}$$

Where,

T_i – irrigation time, h;

E_g – lateral spacing between drippers, m;

E_L – spacing between lateral rows, m;

qe – emitter flowrate, L h^{-1}.

For the simulations, the respective criteria were followed: clay soil with a water content at the field capacity (θ_{fc}) of 0.40; soil water content at the wilting point (θ_{wp}) of 0.24; water application efficiency of the localized drip irrigation system of 95%; 24,480 plants per hectare; 1 emitter per plant; drip flow rate of 1.5 L h^{-1}; lettuce crop coefficients (K_c) at the initial, development, production and maturation stages of 0.5, 0.7, 0.95, and 0.9, respectively; arugula K_c values of 0.4, 0.7, 0.95, and 0.75, respectively; spinach K_c values of 0.4, 0.7, 0.95, and 0.9, respectively; beet K_c values of 0.4, 0.75, 1.05, and 0.6, respectively; lettuce rooting depths (Z_r) of 0.1, 0.2, 0.25, and 0.35, respectively; arugula Z_r values of 0.1, 0.2, 0.25, and 0.35, respectively; spinach Z_r of 0.1, 0.2, 0.3, and 0.4, respectively; beet Z_r values of 0.2, 0.35, 0.5, and 0.7, respectively; and TAW fractions that can be depleted before lettuce, spinach and beet experience water stress (p) of 0.3, 0.3, 0.2, and 0.5, respectively. Lastly, a safety factor of 20% of the RAW was applied so that it does not reach zero and the plant does not enter the stress state. A second simulation followed the same criteria, and only the type of soil was changed to sand with a θ_{fc} of 0.17 and a θ_{wp} of 0.07.

All tests were considered in an irrigation period of 45 days, this value was defined by the authors, with the initial stage ranging between days 0-4, the development stage ranging between days 5-14, the production stage ranging between days 15-35, and the maturation stage ranging between days 36-45.

It is known that each crop stage and the time of 45 days have variations, and they were taken as a reference only for simulation purposes. Thus, since the data used in the tests, such as the irrigation system, were not implemented, there was no need to wait the 45 days for data collection and to obtain the results. Thus, the system was populated with the AWS data for the city of Viçosa, Minas Gerais State, Brazil, where the records were collected in an interval of 45 days, and all data from this simulation are available online[1].

Application development

To facilitate the communication of the irrigation system with the user,a mobile application was developed using the Blynk tool, which works on iOS and Android platforms, with real-time access to the AWS data through the "Processing Center" block. By using the application, the user can interact with the system by requesting real-time, daily, weekly, or monthly information from the sensors and by monitoring when the irrigation system was activated and its water consumption.

The application is available for download through the Blynk app by scanning the QR code (Figure 4).

Figure 4. QR code for app download.

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[1] Available at https://github.com/Jampierre/Mestrado

The entire system built for the AWS communicates with the server via the link blynk-cloud.com. Its communication is carried out by the TCP/IP protocol by default port 80. This ensures that all data processed by the computer are sent to and maintained by the server and can be accessed bythe mobile application.

Results

The total cost of the AWS proposed in this work was approximately US$155 (Table 1). This amount is approximately 40% lower than the market price, which starts from US$258.

Table 1. Values of the items used in building the AWS.

Item	Description	Quantity	Unit value	Total
1	Arduino WeMos D1 R1	1	US$ 12.29	US$ 12.29
2	Font YwRobot 545043	1	US$ 2.69	US$ 2.69
3	PT4056 Lithium Battery Charger Module	1	US$ 1.70	US$ 1.70
4	BMP280 Pressure and Temperature Sensor	1	US$ 6.13	US$ 6.13
5	Real-Time Clock RTC DS3231	1	US$ 7.95	US$ 7.95
6	ABS Plastic Case 158 x 90 x 60mm	1	US$ 6.77	US$ 6.77
7	SD Card Module	1	US$ 2.93	US$ 2.93
8	2GB Memory Card	1	US$ 4.68	US$ 4.68
9	Resistors	3	US$ 0.59	US$ 1.77
10	Jumpers Kit- 10 cm x 120 Units	1	US$ 4.41	US$ 4.41
11	HDC1080 Humidity and Temperature Sensor	1	US$ 15.99	US$ 15.99
12	Mini photovoltaic solar cell BPW34	1	US$ 1.38	US$ 1.38
13	Magnetic Reed Switch	1	US$ 1.15	US$ 1.15
14	7.4V 1.5A Unipower Battery	1	US$ 9.37	US$ 9.37
15	Panel Plate Cell Solar Energy Photovoltaic 12v 5w Watts	1	US$ 41.39	US$ 41.39
16	Articulated Tripod	1	US$ 30.80	US$ 30.80
17	White ABS Premium Filament (200g)	1	US$ 4.19	US$ 4.19
			Final value	US$ 155.77

To validate the AWS, it was installed inside the Main Weather Station (Estação Climatológica Principal - ECP), located in the city of Lavras. Initially, the data were recorded hourly, manually, for comparative purposes, however, with frequent access to the equipment installations, errors/incoherence in the reading of some sensors were found by the team responsible for maintaining the ECP, therefore, collected values present a series of missing data. (Figure 5).

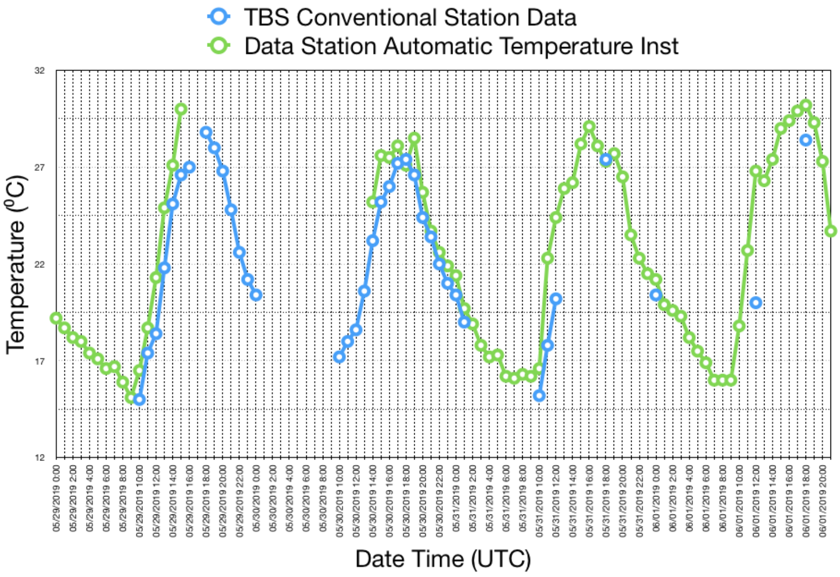


Figure 5. Lavras, Brazil, ECP Temperature x AWS Temperature.

It was also noted that the daily minimum temperature was recorded between 9 and 10 AM, while the maximum were at approximately 5 and 6 PM (Figure5). It is possible to observe in Figure 5 that the reference and automatic station data presented a similar pattern of the values registered because the graph shows the same tendency to rise and descent at the same times.

During the insolation period, when there was an increase in temperature, the data collected by the AWS showed an upper average of 2.7ºC, with atypical peak behavior, which can be explained by wind speed records comparing Figure 6 (Wind graph) with Figure 5 in the same time. The highest measurements were recorded at these times, and the values for the rest of the day were values close to or equal to zero. The upper records inthe insolation hours may have occurred due to a greenhouse effect inside the shelter, which was made from acrylonitrile butadiene styrene (ABS) thermo-plastic and had a smaller diameter when compared to the closed housing, leading to a higher diameter-volume ratio. This observation is confirmed by the fact that, in times with no solar irradiation, the recorded values were close to those of the calibrated station, with an average difference of approximately 0.7°C.

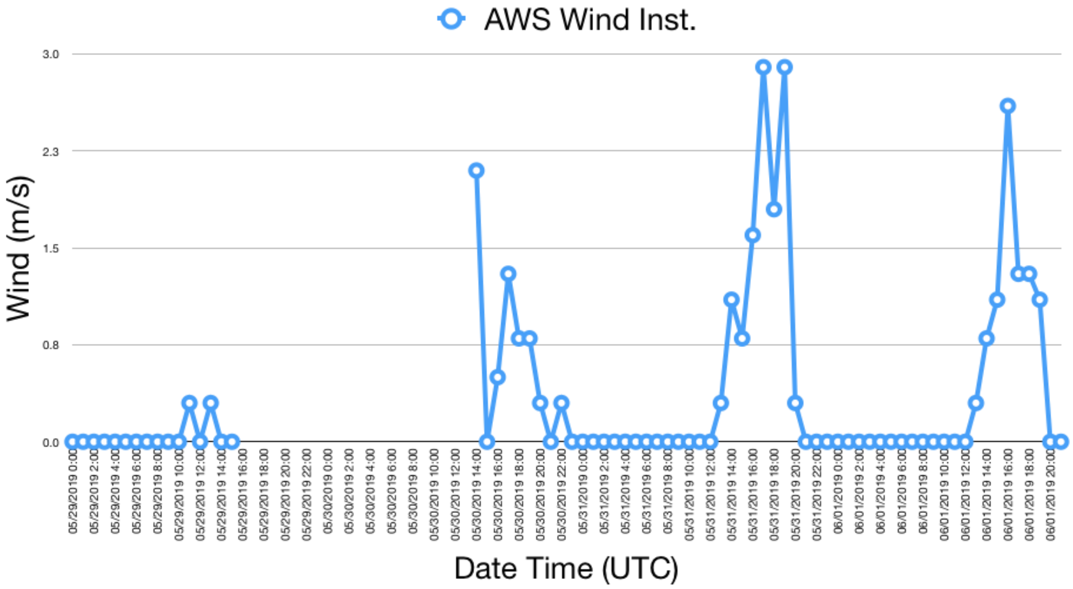


Figure 6. AWS registered wind speed.

The pressure values recorded by the AWS (Figure 7) showed some consistency, with values higher than the average of 1.2 hPa recorded by the ECP barometer.

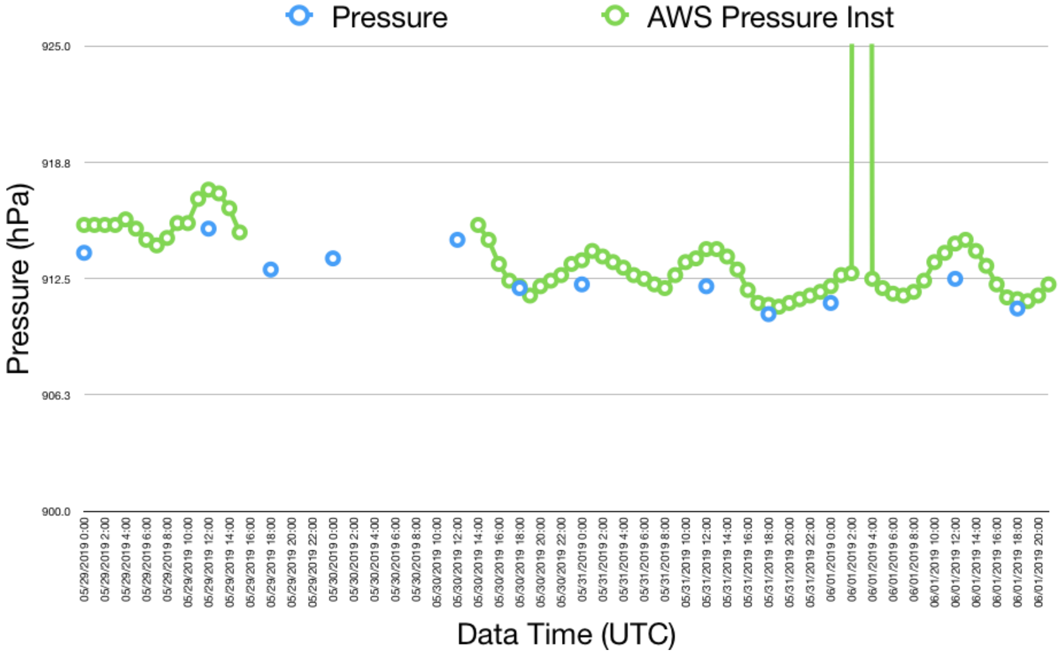


Figure 7. Lavras, Brazil, ECP Pressure x AWS Pressure.

The moisture recorded by the AWS (Figure 8) showed an average difference of +7.7% compared to the data recorded by the ECP.

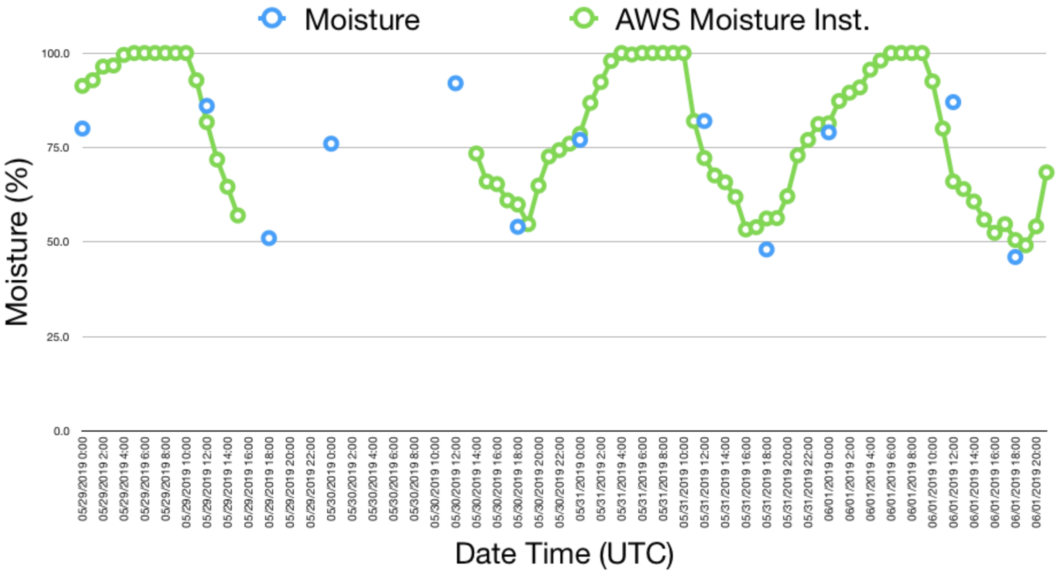
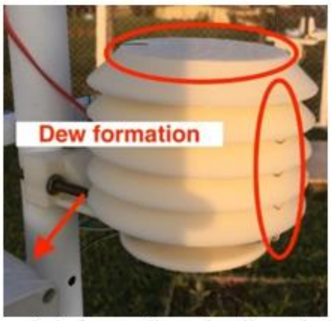
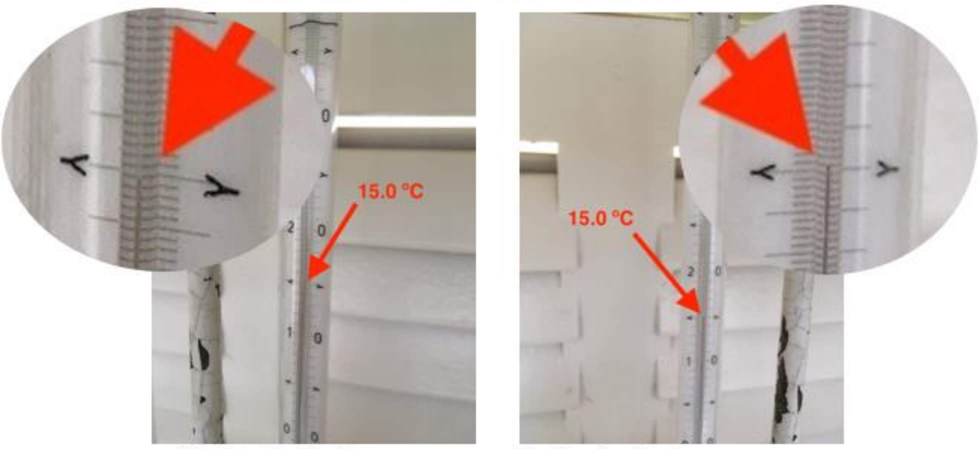


Figure 8. Lavras, Brazil, ECP Moisture x AWS Moisture.

The shortwave radiation was found to be inefficient, with saturated measurements at some times of the day, specifically, between 11 AM and 4 PM (Figure 9).



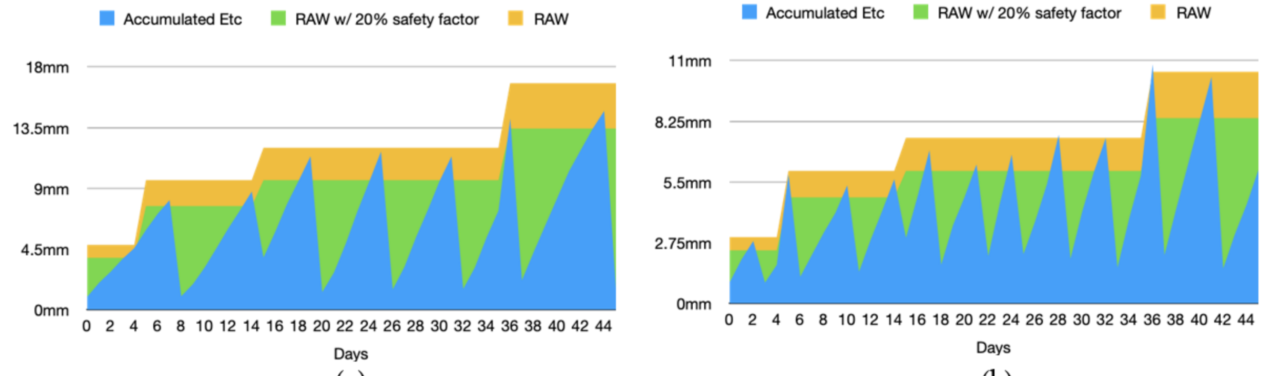
(a) Droplet formation in the shelter



(b) Wet bulb thermometer (c) Dry bulb thermometer

Figure 9. Saturated air with droplet formation in the shed (a) and the temperature ofthe wet bulb (b) and dry bulb (c) equal.

The data of the daily behavior of the crop evapotranspiration accumulated and the thresholds of RAW and RAW with safety factor presented in Figure 10. In terms of irrigation criteria, the system accumulated ET_c until it surpassed RAW with a safety factor. Based on this criterion, for the clayey soil with lettuce planting, the system irrigated 8 times in the period of 45 days, while for the sandy soil, the system irrigated 11 times during the same period of time. On day twenty-eight, for the sandy soil, the accumulated ET_c was higher than the value of RAW, causing the plant to enter the state of water stress because it no longer has water readily available in the soil to retain. For the proposed conditions, the safety factor of 20% was not enough to avoid stress, because, on the previous day, the accumulated ET_c represented 72% of RAW and then ET_c accumulated was 101.7%, that is, an increase of 29.7%, which means 27.1% above the RAW with safety factor. As it is not possible to say what the accumulation of ET_c will be in the growing period, reducing the possibility of irrigation occurring in a state of stress of the plant is due to the increase in the safety factor. Consequently, reducing the irrigation shifts, because with the value of RAW with safety factor of greater, the availability of water in the soil in a safe range will be reduced, making the accumulated ET_c reach it more frequently.



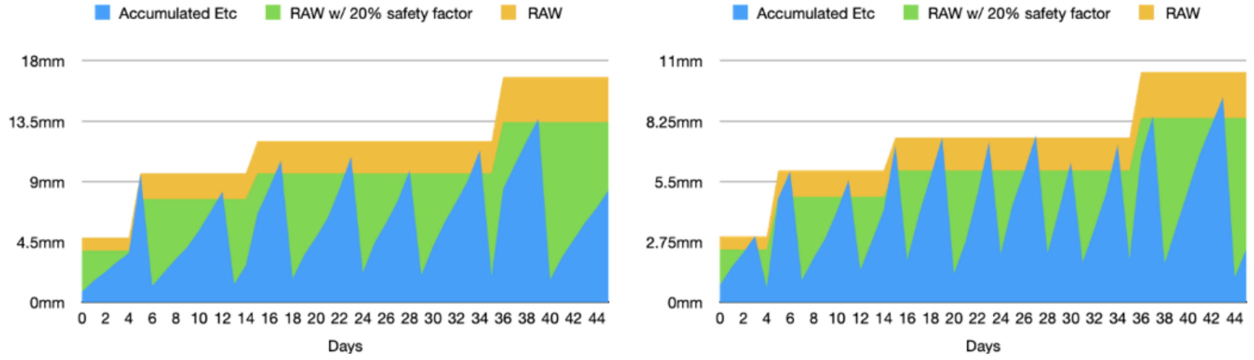
(a) (b)

Figure 10. Lettuce watering shift for clayey (a) and sandy soil (b).

On day five, the system ended the initial culture phase and the development phase began, which changed the values of K_c and Z_r, changing the values of TAW and RAW. At this time, the system considered a new volume of land in which the plant's root started to retain water, and which had not yet been irrigated. In this case, the system accumulated the ET_c on the day plus the difference from the current RAW by the previous RAW, thus leaving all the volume of soil explored by the plant roots moistened.

The clayey soil system obtained an average irrigation every 5 days and did not show any irrigation at a time when the crop was under stress. For sandy soil, the average frequency of irrigation was 4 days and the percentage of 18.18% (2[2] cases in 11) of irrigation in times of stress, with an average water depth of RAW of 2.3%.

In the case of arugula on clayey soil, the crop was irrigated 7 times, as shown in Figure 11, no irrigation occurred during times of stress, while for sandy soil 11 times were irrigated, of which 27.27% (3[3] cases in 11) were under stress. Situations similar to what happened earlier were repeated in the culture of arugula, making the safety factor of 20% not enough to avoid stress. The irrigation shifts for the clayey and sandy soil showed an average frequency of irrigation every 6 days and 4 days, respectively.



(a) (b)

Figure 11. Arugula watering shift for clayey (a) and sandy soil(b).

In the case of clayey soil for spinach cultivation, irrigation was activated 10 times, according to Figure 12, with 10% (1[4] cases out of 10) under stress and for the sandy soil 13 times with 69.2% (9[5] cases out of 13)

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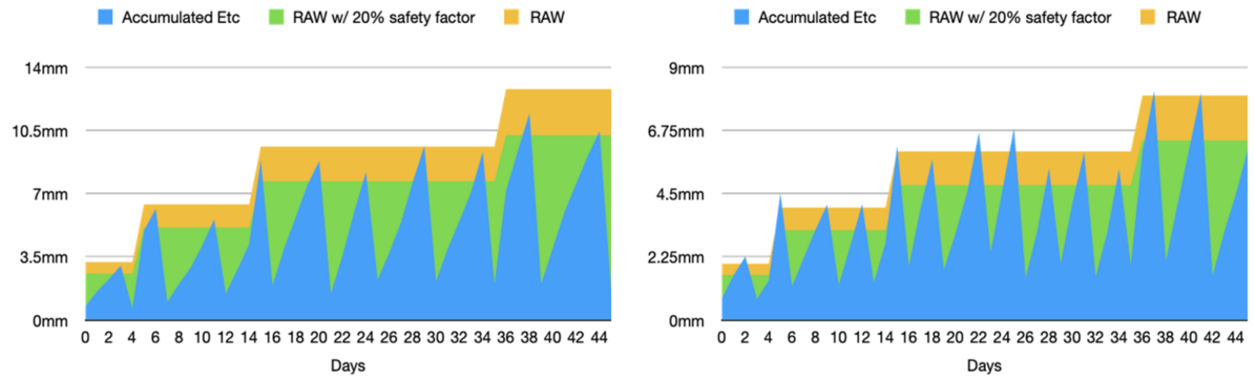
[2] Day 29 and 36
[3] Day 3, 19 and 27
[4] Day 29
[5] Day 2, 5, 9, 11, 15, 22, 25, 37 and 41

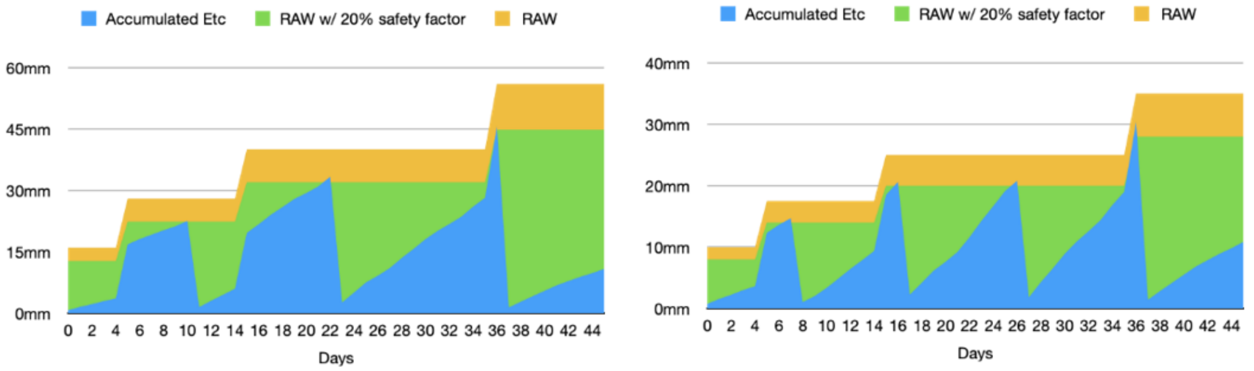
in timesof stress. Both soils (sandy and clayey) had an average of irrigation every 4 days. The high percentage for sandy soil can be justified, taking into account the low value of RAW, causing the irrigation system to be activated morefrequently because the soil holds an insufficient amount of water.



(a) (b)

Figure 12. Spinach watering shift for clayey (a) and sandy soil(b).

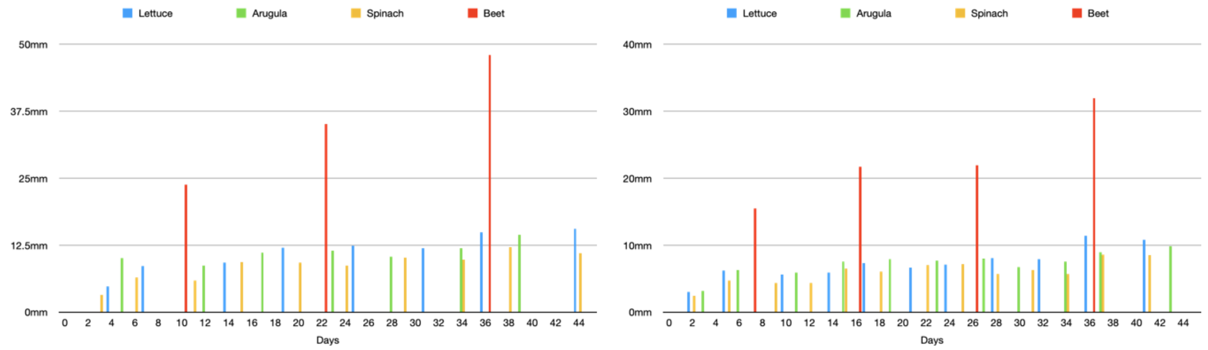
For the beet watering shift (Figure 13) for the clayey and sandy soil, the irrigations proved to be efficient, with the crop irrigated 3 times for the first soil and 4 times for the second, without entering in a stressful situation. The characteristics of the plant, due to its greater length of roots, obtain a greater volume for the absorption of water from the soil, thus, better use of the developed system.



(a) (b)

Figure 13. Beet watering shift for clayey (a) and sandy soil(b).

The water depth of the crops (Figure 14), both for clayey and sandy soil, had their values higher than the accumulated ET_c's. This fact was due to the efficiency of the water application by the drippers, which was 95%, that is, the system irrigates 5% more than the accumulated ET_c value, as it is possible that there are small variations in the flow of the drippers. As seen in Figure 15, the frequency of irrigation in sandy soil was 39.2% higher than in clayey soil.

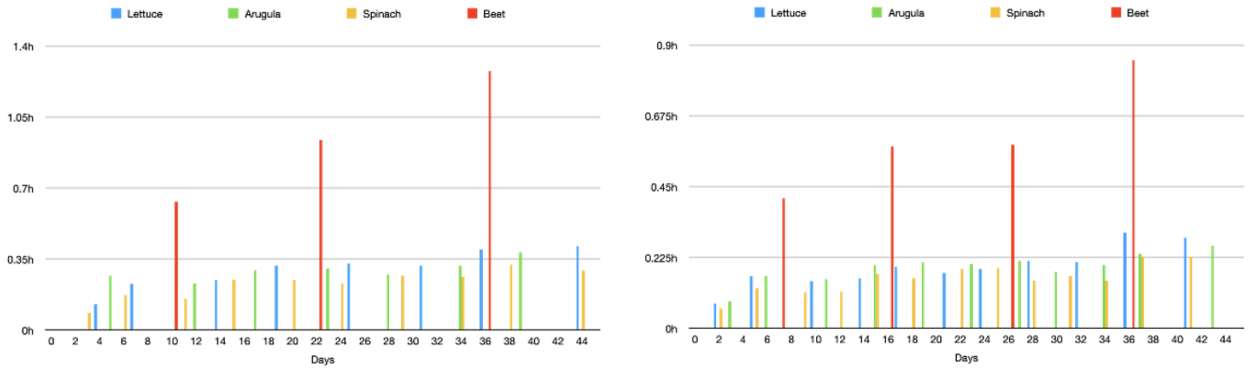


(a) Clay soil (b) Sandy soil

Figure 14. Water depth by crop as a function of days.

The total water supply for the irrigation period for the clayey soil with lettuce planting was 89.2 mm, arugula, 77.9 mm, spinach, 85.3 mm and beet, 106.9 mm. For sandy soil, lettuce planting received 79.8 mm, arugula, 79.4 mm, spinach 77.2 mm and beet, 91 mm. The values presented here followed the calculation example for applying the procedure in irrigation scheduling presented by Allen et al. (1998).

The irrigation time in Figure 15 was calculated using Equation (4). It was observed that for the less frequently irrigated crops, the irrigation time was greater due to a greater accumulation of ET_c. The irrigation time increased over the days because the K_c values of the plant tend to increase due to growth and a greater water need.



(a) Clay soil (b) Sandy soil

Figure 15. Irrigation time in hours.

$$ET_L = ET_0 * K_c \qquad (4)$$

Where,

ET_c - average evapotranspiration for localized irrigation, mm d^{-1};

K_L - adjustment factor due to the localized water application.

Values of field capacity, water readily available for the plant and the safety value of RAW for the system to activate the drippers for the four cultures of the experiments tested in two different soils are shown in Table 2. Spinach showed the highest percentage of irrigation during stress because of the low RAW values and their respective safety factors, leaving a small range (in millimeters), even though it is known that this range still represents 20%. Crops with higher absolute intervals, as in the case of beets, are less likely to have a cumulative ET_c, so the RAW value can increase by more than 20% from one day to the next.

Table 2. Values calculated by the system using input data provided by AWS.

Clay soil			Sandy soil		
			Lettuce		
TAW	RAW	RAW w/ 20%	TAW	RAW	RAW w/ 20%
16	4.8	3.84	10	3	2.4
32	9.6	7.68	20	6	4.8
40	12	9.6	25	7.5	6
56	16.8	13.44	35	10.5	8.4
			Arugula		
AW	RAW	RAW w/ 20%	TAW	RAW	RAW w/ 20%
16	4.8	3.84	10	3	2.4
32	9.6	7.68	20	6	4.8
40	12	9.6	25	7.5	6
56	16.8	13.44	35	10.5	8.4
			Spinach		
TAW	RAW	RAW w/ 20%	TAW	RAW	RAW w/ 20%
16	3.2	2.56	10	2	1.6
32	6.4	5.12	20	4	3.2
48	9.6	7.68	30	6	4.8
64	12.8	10.24	40	8	6.4
			Beet		
TAW	RAW	RAW w/ 20%	TAW	RAW	RAW w/ 20%
32	16	12.8	20	10	8
56	28	22.4	35	17.5	14
80	40	32	50	25	20
112	56	44.8	70	35	28

Conclusion

This study developed low-cost equipment for the automated managementof a localized drip irrigation system in a protected environment. Based on the results, the following conclusions can be made:

-The irrigation schedule was adapted to the requirements of the crops to supply all the water needed for growth.

-Among the tested crops, the safety factor of 20 % proved to be appropriate for lettuce, arugula and beet crops in clayey soil, and for sandy soil, only beet. In this case, increasing the safety factor for crops with greater sensitivity to water is necessary, which is the case of lettuce, arugula and spinach in the sandy soil. A possible solution for not changing the safety factor may be to calculate the ETc less frequently, making irrigation, in addition to having variable days frequencies, be carried out at different times.

-A longer collection period that includes different seasons is necessary to analyze behavior in the four seasons of the year, such as on rainy days or without incident solar radiation, and to validate the AWS data with greater consistency.

-The construction of the pyranometer did not show satisfactory results, and further research on the subject is required.

-The addition of a rain gauge to the AWS could improve the irrigation system because it does not consider rainfall data.

The development of the dedicated AWS resulted in a low-cost, easily used piece of equipment capable of data observation and monitoring of the irrigation system with the use of a mobile application.

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