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PERFORMANCE OF AUTONOMOUS IRRIGATION UNIT VIA MOBILE APPLICATION FOR ARUGULA YIELD

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KEYWORDS

Automation, Internet of things, Protected environment.

ABSTRACT

Due to the increase in water and energy tariffs, in addition to the limited amount of these resources, the automation of irrigation can help farmers to increase the production of agricultural crops. Therefore, the objective of this research was to evaluate different irrigation managements between manual and automatic in the production of arugula in a protected environment, in order to determine the productive potential in the cultivation of vegetables. The experiment was conducted in randomized blocks with four irrigation management strategies, divided into automatic and manual managements: automatic irrigation management via soil (IAS); automatic irrigation management via climate (IAC); manual irrigation management via soil (IMS) and manual irrigation management via climate (IMC). The treatments were applied to the arugula (*Eruca Sativa L.*) crop during two production cycles, and their effect on biophysical aspects of plants and irrigation water productivity was evaluated. For the fresh mass variable, the IAC (17.75 g plant^{-1}), IAS (12.38 g plant^{-1}), and IMC (8.63 g plant^{-1}) treatments, in the 1st cycle, were statistically similar to each other, whereas in the 2nd cycle, only the IAC (16.29 g plant^{-1}) and IAS (19.80 g plant^{-1}) treatments had this statistical similarity. Automatic managements can be recommended based on this research, however, considering the financial difficulties of the small farmer, IMC may be a desirable option in unfavorable economic conditions.

INTRODUCTION

Water scarcity and the increase in water and energy tariffs, as well as new directions in which the Brazilian agriculture is heading, with the need for healthier, higher quality products, with less pesticides and cheaper workforce, make agriculture processes undergo modernization in different ways. That includes irrigation methods, which have become increasingly automated (Silva et al., 2020).

Among numerous forms of irrigation updates, the use of moisture sensors, based on several methodologies, can be included. These are connected to computers and controllers that, through digital signals, interlink irrigation systems, controlling the entire irrigation management and nutrient application (Souza et al., 2019b; Silva et al., 2020). Another form of automation is related to the use of computer programs, which communicate remotely with the equipment, such as center pivot irrigation systems, where despite working independently, the whole set is combined in a continuous and organized operation to maintain a linear irrigation structure (Silva et al., 2020). This innovation process seeks to reduce electricity and water costs, in addition to those regarding workforce.

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Although it is a great solution to cheapen processes and have greater control over planting, the insertion of automated systems remains a challenge. Because, for the realization of such a process, a high initial investment and specialized workforce are necessary. Therefore, many small farmers often end up being excluded from these methods (Soares Filho & Cunha, 2015), since the return on vegetables production, such as arugula (*Eruca Sativa L.*), is low and many times not worth the investment. To mitigate the situation, the use of cheaper tools and systems that, although simpler, are enough to carry out functions accurately, may lead small farmers to modernization (Souza et al., 2019b).

Robotics (Cardoso et al., 2020), artificial intelligence (Megeto et al., 2020), and machine learning are already present in society's daily life, from education to agriculture. Thus, it is totally plausible to insert automated units into small rural production. Just as important as the system performance, so is the communication with sensors and other inspection methods, in order to maintain a concise information network and create a security relationship with the data (Oliveira, 2017). This communication can be via cables or even wireless systems, such as radio frequency (Monteleone et al., 2020), which may reduce the working time of small farmers in irrigated crops somehow. Hence, this paper aims to evaluate different irrigation managements between manual and automatic for arugula yield in a protected environment, in order to determine the productive potential in the cultivation of vegetables.

MATERIAL AND METHODS

The environment used for the application, tests, and experiment was a greenhouse of the Department of Agricultural Engineering – DENA, located in the weather station of the Federal University of Ceará – UFC, Pici campus, at 3°44'45" S, 38°34'55"W, and 19.5 m above sea level. The greenhouse is 6.25 meters wide and 12 meters long, and has a 0.10 mm thick low-density polyethylene film simple arched roof and a black shade fabric (50%) in its interior. During the cycles, room temperature (°C), relative humidity of the air (%), solar radiation, and class A pan evaporation (mm day^{-1}) were monitored. The average data every ten days, measured inside the protected environment, can be observed in table 1.

TABLE 1. Weather conditions during the experimental period.

Days	1st Cycle					
	Tmax	Tmin	Tmean	RH	Rn	ECA
	---------------------	(°C)	---------------------	(%)	(MJ m^{-2})	(mm)
10	37.4	25.6	29.7	61.5	9.4	5.5
20	38.9	25.7	30.4	49.4	12.8	5.3
30	39.0	25.9	25.5	51.0	11.4	5.0
Days	2nd Cycle					
10	37.5	25.9	30.0	59.0	7.5	4.8
20	36.9	25.6	29.0	63.5	6.3	5.2
30	36.9	25.0	30.0	64.8	6.8	5.5

Tmax – maximum temperature, Tmed – minimum temperature, Tmean – mean temperature, RH – relative humidity, Rn – net solar radiation, ECA – Class A pan evaporation.

The crop used was arugula (*Eruca Sativa L.*), which was sowed in polystyrene trays with 200 cells, using coconut powder substrate (50%) and vermiculite (50%). Two seeds per cell were sowed, and after germination and emergence of the third leaf, the most vigorous ones were selected, while plants with some deficiency or low vigor were thinned. Thirty days after sowing, the plants were transplanted into seedbeds and irrigated with constant depths for the crop establishment in the field.

Fertilization was performed via fertigation with doses of 40 kg ha^{-1} of N, 300 kg ha^{-1} of P_2O_5, and 100 kg ha^{-1} of K_2O, as recommended by Trani & Raij (1997). For this purpose, the following fertilizers were used: Urea (45% of N), MAP (12% of N and 61% of P_2O_5), and Dripsol NKS (45% of K_2O and 12% of N). Fifty percent of the nutrients were applied at 10 days after transplanting (DAT), and 50% at 20 DAT. Two production cycles were conducted, the first one from December 17, 2020 to January 16, 2021; and the second from February 1, 2021 to March 3, 2021.

The soil used in the experiment was removed in a layer of 0-20 cm and classified as Red-Yellow Acrisol (EMBRAPA, 2013), with the following physical characteristics: sand: 62%, silt: 10%, clay: 28%, and bulk density: 1,52 g cm^{-3}. The chemical characteristics can be observed in Table 2.

TABLE 2. Soil chemical properties.

Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$H^{+}+Al^{3+}$	Al^{3+}	SB	CEC	pH	EC	C	N	OM
----------------------------------				(cmol$_c$ kg^{-1})			----------------------------------		(dS m^{-1})	----------	(g kg^{-1})	----------
1.20	0.60	0.23	0.36	1.98	0.15	2.60	4.37	6.0	0.35	6.48	0.61	11.17

SB – sum of bases, CEC – cation exchange capacity, EC – electrical conductivity, OM – organic matter.

The experiment was carried out in randomized blocks with the following treatments related to irrigation use: automatic irrigation management via soil (IAS); automatic irrigation management via climate (IAC), manual irrigation management via soil (IMS), and manual irrigation management via climate (IMC). The experimental plot was composed of seedbeds with an area of 1.5 m x 0.30 m, where five plants were spaced 0.30 m apart. Each treatment had eight experimental plots, totaling 32 plots.

Manual irrigation management via soil was performed using puncture tensiometers (Franco et al., 2017), measured by a digital tensimeter with the aid of a soil-water characteristic curve (Figure 1) to determine soil moisture, and, subsequently, depth (0-20 cm), through which the depth irrigation was determined.

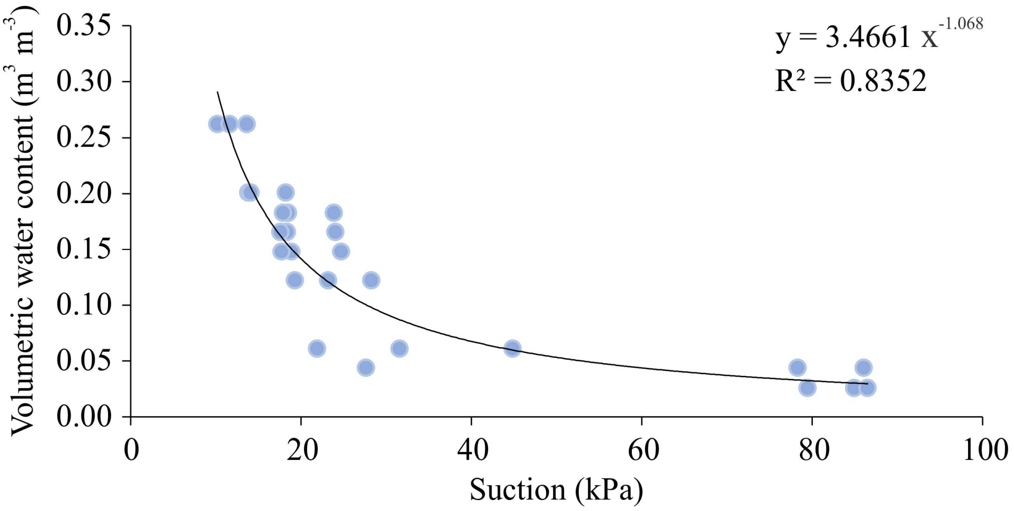

FIGURE 1. Soil water characteristic curve for irrigation management purposes.

In the IMS, the application was performed manually, with the multiplication of irrigation water depth over the experimental plot area, using a graduated cup. A constant depth was created for the initial establishment of the crop. Five days after transplanting (DAT), the moisture content was obtained, and the necessary volume per seedbed was calculated.

The manual irrigation management via climate (IMC) was conducted through the crop evapotranspiration (ETc), obtained by determining the reference evapotranspiration (ETo), using a Class A pan, with the evaporation measurements and tank coefficient (Kp), in addition to the crop coefficient, as recommended by Gültekin & Ertek (2021). In the IMC, the irrigation depth application was carried out manually, with the multiplication of ETc over the experimental plot area, using a graduated cup. The coefficient of arugula cultivation used was based on information obtained by Villares et al. (2011), with values of 0.29 (0-8 DAT), 0.52 (9-16 DAT), 0.93 (17-24 DAT), and 0.87 (24-30 DAT).

The IAS device was assumed as a tool to water plants according to soil moisture measurements assessed by buried sensors that worked based on the directly proportional relationship between the soil conductivity and its water content. An immersive electrode-type moisture sensor was used, with a corrosion-resistant metallic material, and data stored in the memory of a microcontroller installed in the protected environment, whose information was sent to an online server accessible via mobile application. The control system was developed on a NodeMCU (platform based on ESP8266), while the smartphone application was developed on the Blynk® platform (Melo et al., 2020), which allows a greater integration between microcontrollers and smart devices via MQTT (Message Queue Telemetry Transport) communication, based on the principle of programming for the internet of things (IoT), according to Oliveira (2017).

The program structure is divided into soil moisture reading, data saving in a microcontroller, which transmitted this data in real time to the user, so that they could be kept up to date on the crop situation, and, finally, solenoid valves activation (12v) to release the irrigation water depth. Each operation step can be observed in Figure 2, that represents the program execution flowchart (Figure 2A).

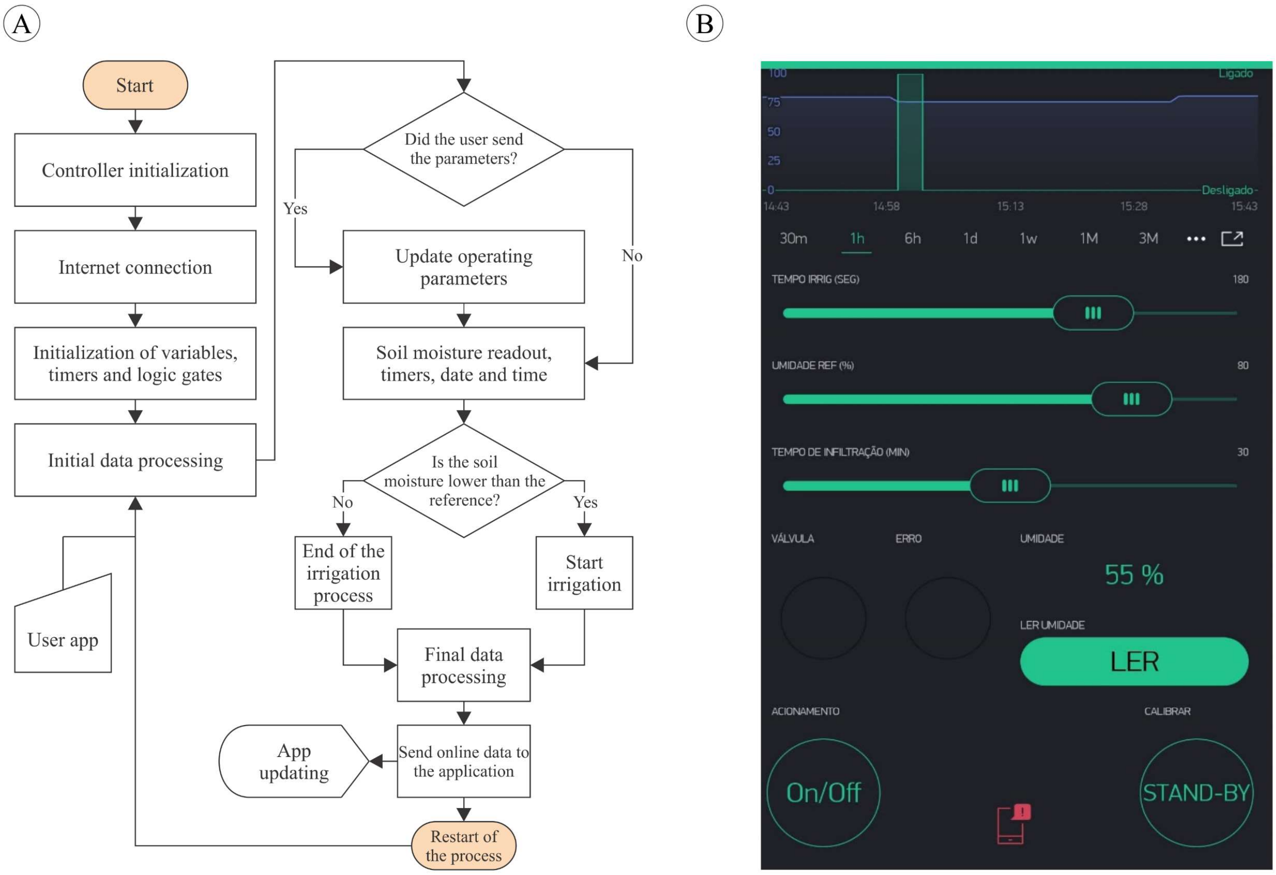

FIGURE 2. IAS device working flowchart (A) and interface (B).

During each cycle of the process, the system updated the user interface to have real-time information, where in the application (Figure 2B), there is the option of manual and automatic activation, chosen according to the user needs. In the manual mode, the user has control of real-time information regarding soil moisture in seedbeds, and can control the irrigation activation. In the automatic mode, the user defines the parameter for the system activation, which is the desired soil moisture (θ, cm³ cm^{-3}), then, the system starts operating and does its utmost to maintain the pre-established conditions with irrigation at intervals of 10 minutes (pulse drip irrigation), until it reaches pre-established moisture content (Figure 3).

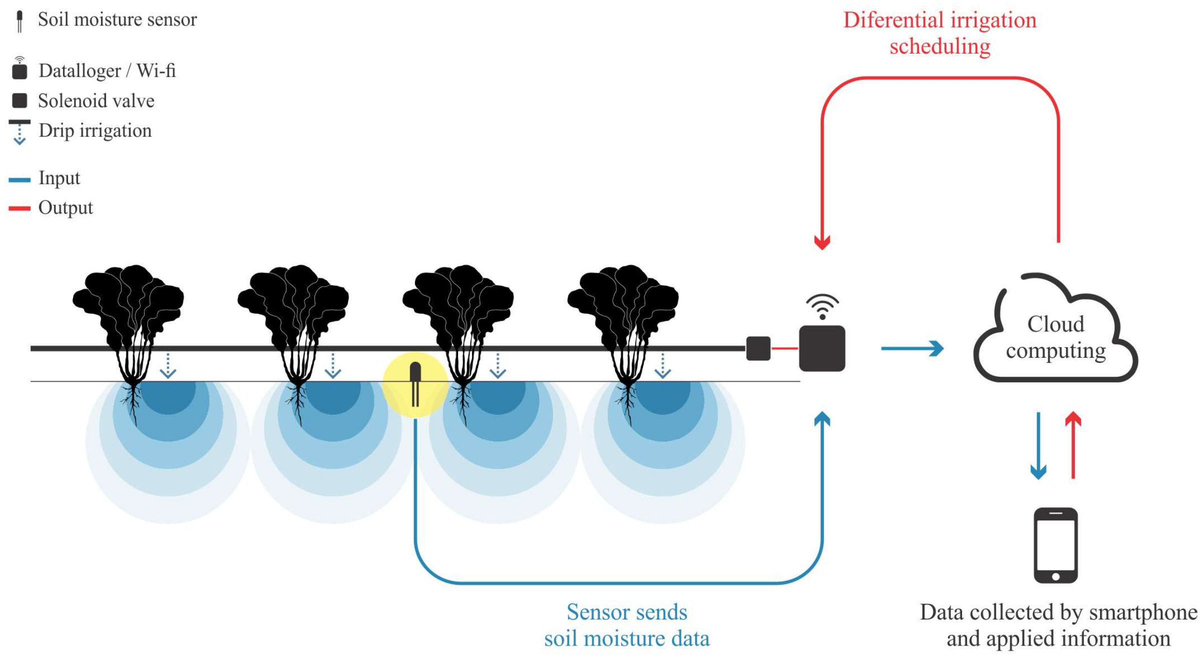

FIGURE 3. Automatic soil moisture-based irrigation management using the mobile application.

Irrigation was performed using a drip tape with a flow rate of 0,8 L h^{-1}. The emitters flow rates were measured during the experiment, obtaining the Christiansen uniformity coefficient (CUC) of 92% and performing the total irrigation needed (ITN), with a system efficiency of 90% (Lozano et al., 2020).

Automatic irrigation management via climate (IAC) consisted of an autonomous system responsible for collecting temperature and relative humidity of the air using a DTH11 sensor, in addition to the solar radiation from each day, with the aid of the LDR (Light Dependent Resistor) module, both connected and stored in the memory of a microcontroller (ESP8266) installed in the protected environment. Its information was sent to an online server accessible via mobile application (Figure 4), developed on the Blynk® platform with MQTT communication (Oliveira, 2017). The controller calculated the crop evapotranspiration using the Heargreaves equation (Lima Júnior et al., 2016), and consequently the irrigation water depth applied in the seedbeds, converting it to liters by multiplying of irrigation depth value over the experimental plot area. Irrigation was divided into 10-minute intervals (pulses), until it reached its total application. The system efficiency (90%), flow rate, and water release (solenoid valve) were carried out similarly to the IAS treatment.

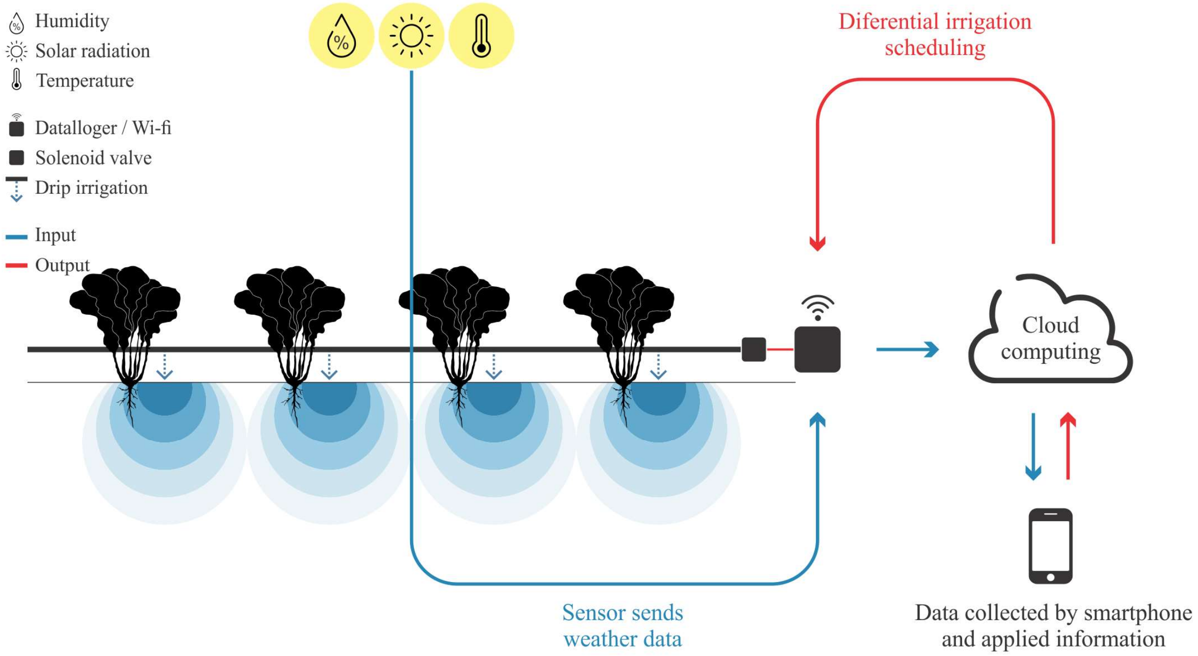

FIGURE 4. Automatic weather-based irrigation management using the mobile application.

The application use is intuitive, where the user has the manual or automatic use option. In the manual mode, it is possible to take the sensors reading and perform a timed irrigation. In the automatic mode, in turn, the user must enter the desired number of daily irrigations, along with the timetable, and also the values equivalent to the crop coefficient, irrigation area, irrigation efficiency, number of drippers per plant, and dripper flow rate. Each operation step can be observed in Figure 5A, that represents the program execution flowchart and the interface of the developed application (Figure 5B).

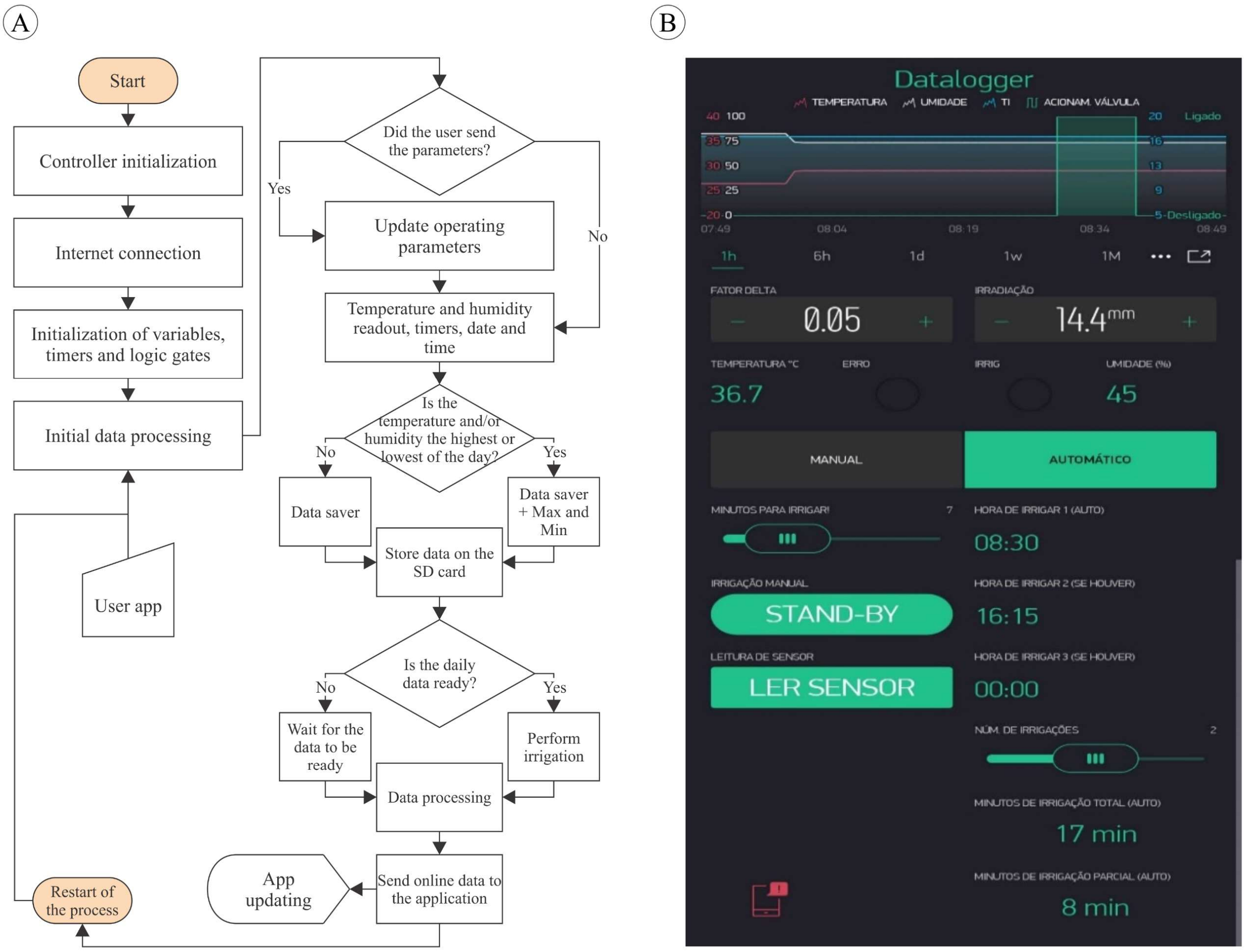

FIGURE 5. IAC device working flowchart (A) and interface (B).

The following variables were evaluated during the experiment: fresh weight (FW) and dry weight (DW) of plants, obtained through a 0.01 g precision scale, number of leaves per plant (NL), which was determined by counting the number of total leaves present in each plant in all experimental units, aerial part height (APH), each performed every ten days after transplanting (DAT), with the aid of a millimeter ruler (cm). After collecting and weighing the samples, their leaves were removed and the leaf area (LA) of each sample was checked. For that purpose, the Leaf Area Meter (Li-Cor LI 3100) was used, in order to determine the leaf area (cm²) in all studied treatments.

The irrigation water productivity (IWP, kg m^{-3}) was calculated from the relationship between crop productivity (Ya, kg ha^{-1}), through the aerial part fresh weight, and water volume corresponding to the total irrigation depth (ITN, m^3 ha^{-1}) applied in each cycle (Pereira et al., 2012).

Statistical analysis was first conducted by testing the normality of the data, and subsequently, through the analysis of variance (ANOVA) at 5% probability. Significant data were submitted to Tukey's test at 5% probability.

RESULTS AND DISCUSSION

Concerning the IMS, the values of accumulated irrigation depth in the crop were 137.5 mm in the 1st cycle, and 93.8 mm in the 2nd (Table 3), with an average daily depth of 4.6 mm day^{-1} and 3.1 mm day^{-1} respectively. In the IMC, an irrigation depth of 116.7 mm was observed, with a daily consumption of 3.9 mm day^{-1} in the 1st cycle, and 75.0 mm $cycle^{-1}$ with an average daily consumption of 2.5 mm day^{-1} in the 2nd cycle.

TABLE 3. Irrigation depths applied by each irrigation management strategy.

Irrigation depth	IMS	IMC	IAS	IAC
	1st Cycle			
ITN (mm $cycle^{-1}$)	137.5	116.7	90.4	95.9
ITN (mm day^{-1})	4.6	3.9	3.0	3.2
	2nd Cycle			
ITN (mm $cycle^{-1}$)	93.8	75.0	142.5	90.2
ITN (mm day^{-1})	3.1	2.5	4.7	3.0

The values of the 1st ICM cycle are close to those obtained in the IMS, and similar to the values obtained by Cunha et al. (2018), possibly due to the obtained ETc values being similar in methodology. Elevated temperatures observed during this study may have influenced the increase in water consumption of the plants.

Regarding the IAS, 90.4 mm cycle^{-1} were applied, with an average depth of 3.0 mm day^{-1} in the 1st production cycle. In the 2nd cycle, 142.5 mm cycle-1 were applied, with an average depth of 4.7 mm day^{-1}. In the 1st IAC cycle, 95.9 mm of water were applied, with an average depth of 3.2 mm day^{-1}, while 93.1 mm were applied in the 2nd cycle, with an average depth of 3.1 mm day^{-1}. Souza et al. (2019b), while studying semiautomatic irrigation in tomato crops, showed the effectiveness of TDR moisture sensors for the proper irrigation management. According to Silva et al. (2020), soil moisture sensors can be an important tool for the proper irrigation management, since they can irrigate at the exact moment when the soil is in the process of moisture loss, immediately replacing what the crop consumed.

Growth variables

According to the analysis of variance, the irrigation management factor had a significant effect for the APH variable at 20 DAT ($p < 0.05$) and 30 DAT ($p < 0.01$) in the 1st production cycle. Constant water availability throughout the cycle may have influenced the distinction between irrigation managements as of 20 DAT (Moline et al., 2015).

In the 2nd cycle, for the APH variable at 10, 20, and 30 DAT, a significant effect ($p<0.01$) for the irrigation management factor was observed. Due to the differentiation of each method, the accumulated depth values possibly influenced this factor. That fact was observed in several studies (Cunha et al., 2018; Moline et al., 2015; Cunha et al., 2013), which proves that the addition of water increases crop vigor and changes its growth. However, the stress caused by water excess may also be a factor to be considered in this evaluation, as stated by Souza et al. (2019a), in studies on water table depth and its influence on arugula crop productivity, where the authors observed that excessive water can harm plant development.

According to data shown in Figure 6, for the 1st production cycle, the IAC provided higher values for the plant height variable, 11.88 cm (Figure 6A), and 18.63 cm (Figure 6B), along with the IAS method, which do not statistically differ from each other when submitted to Tukey's test at 5% probability. The IMS treatment revealed the lowest values (5.63 cm) at 20 DAT and 30 DAT (8.13 cm). The observations in this study differ from those shown by Moline et al. (2015), who obtained values of up to 25 cm for arugula height with 100% of ETc replacement in the southern region of Rondônia.

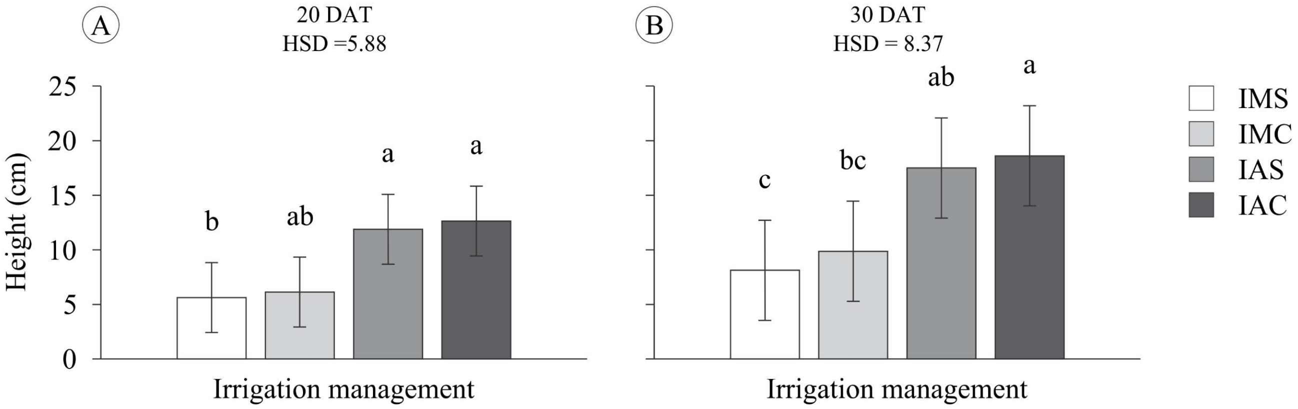

FIGURE 6. Tukey’s HSD results for comparison between means of plant height achieved by each irrigation management throughout the first cycle. The same letter above bars indicates a not statistically significant difference between the means, assuming a 5% significance level.

Results of the 2nd cycle for the plant height variable can be observed in Figure 7. According to data, the IAS showed higher values for the variable studied in all evaluation periods. At 10 DAT (Figure 7A), values of 8.6 cm were observed for the IAS, being statistically similar to those of the IAC (8.1 cm). Possibly, the demand for water during this crop phenological period is lower, which did not lead to differences between these treatments.

At 20 DAT (Figure 7B), the IAS treatment obtained the highest value (17.86 cm) among the other treatments, while the IAC, IMC, and IMS treatments did not statistically differ from each other. At 30 DAT (Figure 7C), the IAS and IAC obtained the highest values (21.64 and 18.32 cm) for the variable studied, not differing from each other ($p<0.05$). The IMS, IMC, and IAC did not statistically differ from each other.

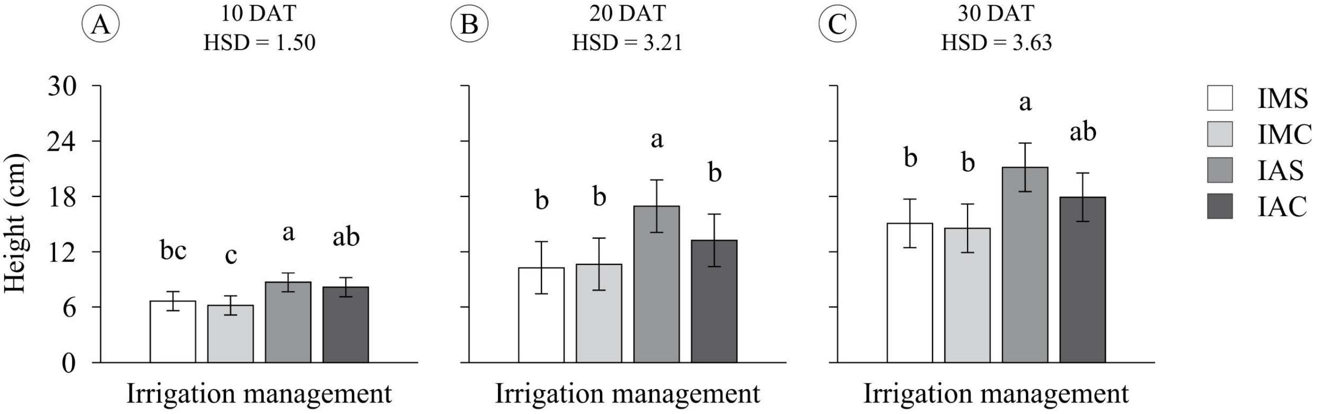

FIGURE 7. Tukey's HSD results for comparison between means of plant height achieved by each irrigation management throughout the second cycle. The same letter above bars indicates a not statistically significant difference between the means, assuming a 5% significance level.

Despite the irrigation criteria established for arugula crops, water stress may have caused the differences in treatments. Such stress may have been caused by the only time when manual irrigations were performed, during the day (9 AM), unlike the automatic system irrigations, which were managed by pulses throughout the day. That could be related to the highest productivity values observed in automatic management. This fact may be considered an important factor, since punctual application can generate water savings. Numerous studies have debated the use of pulse drip irrigation. Maller et al. (2019), while studying soil moisture in a drip irrigation system, concluded that pulsating irrigation tends to distribute water in the soil similarly to continuous irrigation. Nevertheless, Almeida et al. (2015), in studies on pulse drip irrigation, observed a reduction in water use and an increase in the productivity of lettuce (*Lactuca sativa L.*), which is a crop with an elevated water content in its constitution, similar to arugula.

Production variables

According to the analysis of variance (F-test), the leaf area (LA) and aerial part fresh weight (APFW) variables had significant differences ($p<0.05$) for the treatments studied in the two production cycles. This fact may have occurred due to different water applications in the soil (pulse drip irrigation and continuous irrigation) in the studied irrigation managements. Studies such as those by Cunha et al. (2018) and Moline et al. (2015) revealed significant differences due to the variation of irrigation depths for these variables.

Figure 8 shows the arugula crop after its harvest. Treatments using automatic irrigation management showed a greater weight in relation to those using manual irrigation management for the 2nd cycle. These results can be observed in Figure 9, where the IMS treatment was the only one that showed a statistical difference regarding LA data in relation to the IAC in the 1st cycle (Figure 9A) and IAS in the 2nd cycle (Figure 9C) among the studied treatments ($p<0.05$), thus being the worst result.

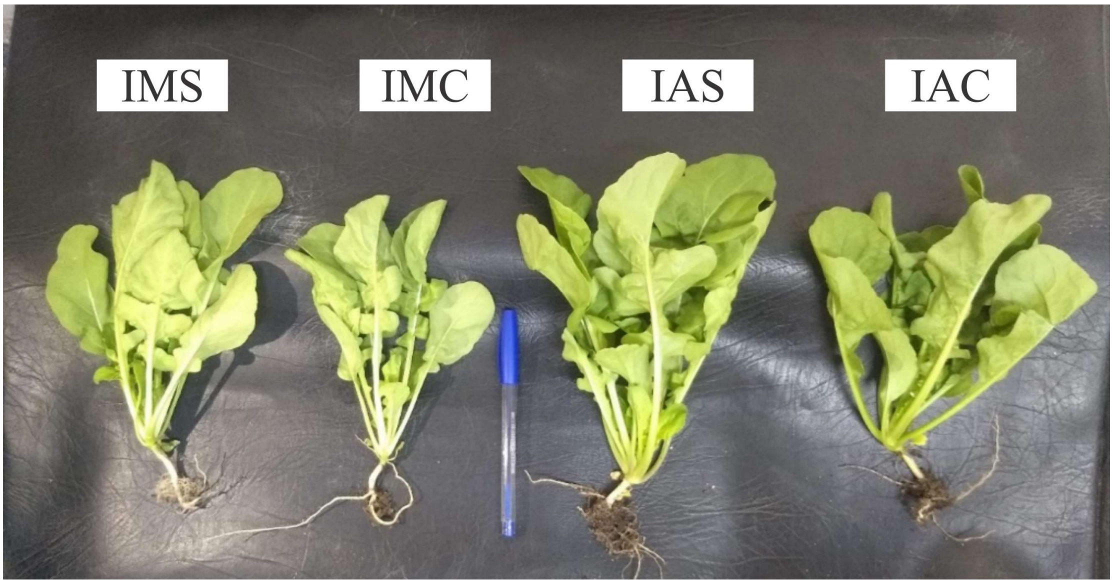

FIGURE 8. Arugula plants at 30 DAT according to each irrigation management strategy.

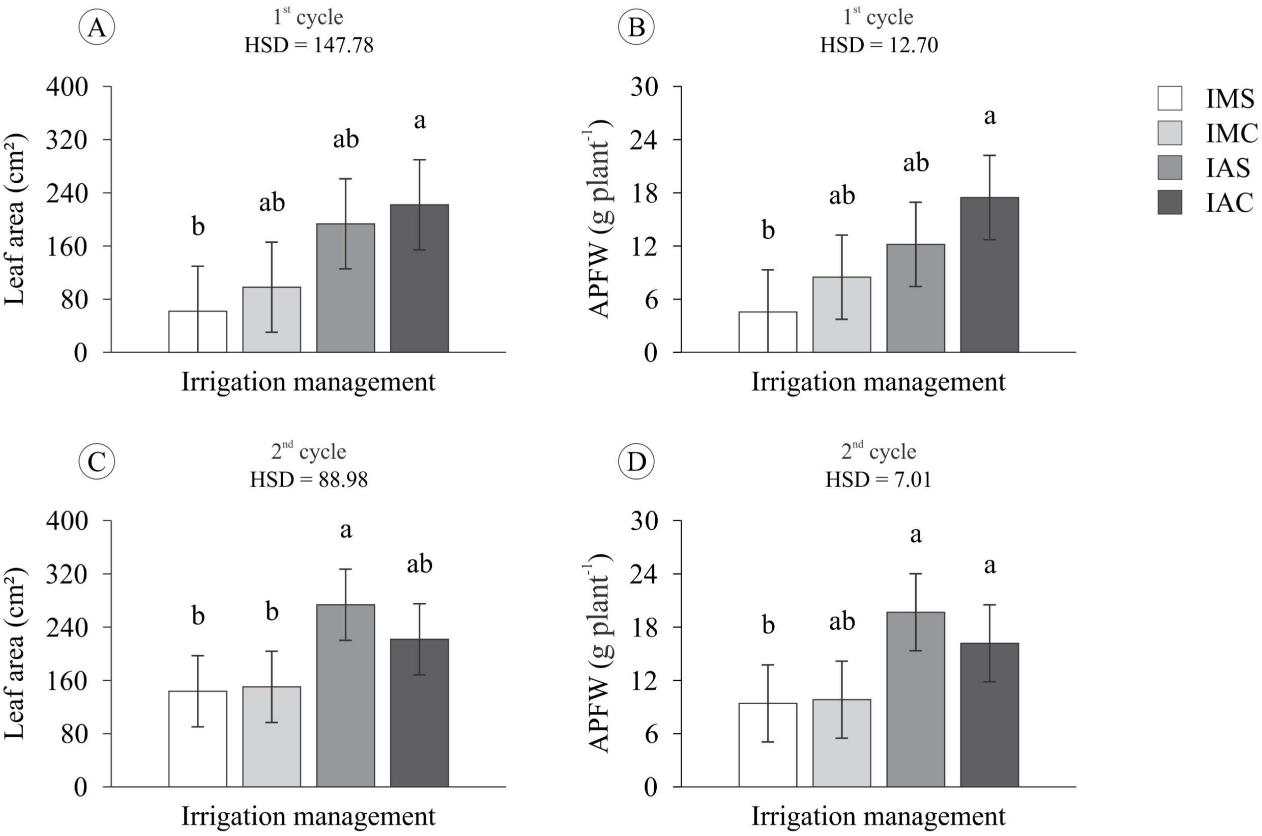

FIGURE 9. Tukey's HSD results for comparison between means of yield parameters achieved by each irrigation management throughout the first and second cycle. The same letter above bars indicates a not statistically significant difference between the means, assuming a 5% significance level.

In the 2nd cycle, the leaf area variable (Figure 9C) between automatic treatments were similar, according to the values observed for the IAC (231.50 cm²) and IAS (285.64 cm²). In terms of production viability, irrigation management through the use of automatic systems can be considered satisfactory, as it showed higher values in most of the results studied, confirming its viability in the technical aspect of vegetables production. According to Silva et al. (2020), the automation of irrigation systems is a necessity nowadays, due to the occupation of farmers with other activities, such as farming, beekeeping, etc. However, concerning the economic issue, these authors emphasize that the financial condition of each farmer is a determining factor for the use of automatic or semi-automatic systems (Souza et al. 2019b). Other inputs, such as the cost of water (Frizzone, 2007), fertilizers (Caixeta et al., 2017), and the economic returns provided by produced vegetables can be determining factors for the implementation of automation in irrigated systems.

For the APFW variable in the 1st and 2nd production cycles (Figure 9B and 9D), the IAC (17.75 g plant^{-1} in the 1st cycle and 16.29 g plant^{-1} in the 2nd cycle), IAS (12.38 g plant^{-1} in the 1st cycle and 19.79 g plant^{-1} in the 2nd cycle), and IMC (8.63 g plant^{-1} in the 1st cycle and 9.88 g plant^{-1} in the 2nd) treatments were statistically similar in both evaluated cycles. Thus, the IMC is expected to be a viable option for irrigation management in situations where there is a lack of economic resources to implement the automation of irrigation systems in small properties, since the ETc monitoring in small areas can be conducted more easily and practically through the use of a Class A pan. Moline et al. (2015) observed values greater than 80 g in arugulas that received depths with 100% of ETc. Cunha et al. (2013) observed FW values (17.03 g plant^{-1}) consistent with those shown in this experiment, revealing the variability of this crop production according to the production methods used.

Irrigation water productivity

The IWP was influenced ($p<0.05$) by the irrigation management factor only in the 1st production cycle. As observed throughout the study, there was a tendency to reduce the irrigation depths applied in the 2nd production cycle treatments, which may have contributed to the increase in IWP (Figure 10). According to Pereira et al. (2012), high indexes of IWP can be obtained in crops subjected to water deficit. Nonetheless, the results with the reduction of applied water may not be satisfactory, especially in small properties, hence the necessity of a proper irrigation management to maximize this index.

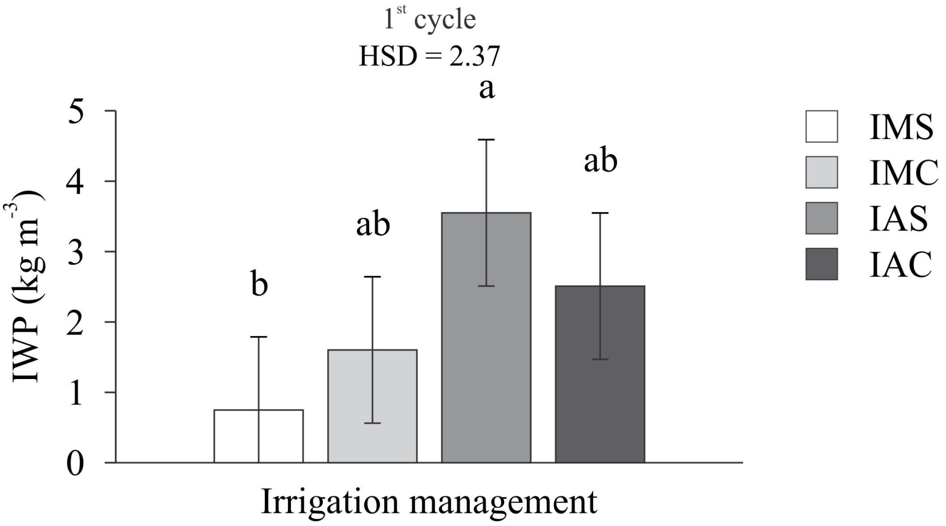

FIGURE 10. Tukey's HSD results for comparison between means of the irrigation water productivity achieved by each irrigation management during the first cycle. The same letter above bars indicates a not statistically significant difference between the means, assuming a 5% significance level.

For the IWP variable, the IAS (3.55 kg m^{-3}), IAC (2.51 kg m^{-3}), and IMC (1.60 kg m^{-3}) treatments did not statistically differ from each other. According to Frizzone (2007), in order to develop great irrigation strategies, it is necessary to use relationships between applied water and productivity, namely production functions. Therefore, the IWP is related to the production mode to which the crop is subjected, mainly to the use of water and its application method, thus leading to consider automation a necessity to increase the IWP (Silva et al., 2020). That can be observed for the automatic treatments in this study, however, the IMC treatment should be taken into account in unfavorable economic conditions for the implementation of automation.

CONCLUSIONS

The automatic irrigation systems presented here can be suitable to increase water use efficiency, making water management easier in cultivation, reducing workforce costs, and increasing production.

Regarding manual irrigation management, the irrigation via climate with the use of a Class A pan, in this study, showed the best performance. Thus, it is an option when there is no intention of initially investing in technology, and the equipment for climate data collection is already available.

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