

TECHNICAL PAPER**LOW-COST AUTOMATION OF FERTIGATION WITH PROGRAMMABLE LOGIC
CONTROLLER AND GAS-FILLED SENSORS**Doi:<http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v37n2p394-402/2017>**RICARDO DE S. BEZERRA¹, ADÃO W. P. EVANGELISTA^{2*},
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ABSTRACT: The aim of this study was to develop and evaluate a low-cost automation system for management of different fertigation regimes in tomato plants (*Solanum lycopersicum* L.) grown in a protected environment. The system consisted of an irrigation controller coupled to substrate moisture sensors and to a programmable logic controller (PLC). Four water regimes and nutrient supply levels were considered during evaluations. While developing, functional tests were performed to the automation system. Moreover, a cost-benefit analysis for the assembling of the system was carried out. As result, we noted that the automation system was efficient for controlling fertigation. It showed no problems regarding malfunction, still presenting a lower cost if compared to commercial controllers.

KEYWORDS: water management, microcontroller, matrix potential.

INTRODUCTION

The advent of microprocessors and microcontrollers has enabled the development of complex systems of automation control as the ones used in irrigation management and intelligent farming machinery and implements for precision agriculture. With this new way of agricultural production optimization, old concepts have been changed, and others incorporated into farming processes. Therefore, the perspective of how to approach and manage agricultural systems has been modified each day (SORENSEN et al., 2010; MELO JÚNIOR et al., 2013).

Agricultural automation can lower labor costs since it reduces repetitive tasks. Therefore, automatic systems for irrigation and fertigation monitoring and controlling are effective in applying water and fertilizers at appropriate time and amounts, thus, optimizing the use of these resources (PINTO et al., 2013; VIEIRA et al., 2011). On the market, there are several models of controllers connected to soil moisture sensors allowing irrigation management by monitoring soil water content. This technology points to the exact moment of irrigating, in addition to programming the water depth to be applied. Some of these controllers are simple, having only one control branch, therefore, with low acquisition cost; however, others are more sophisticated and costly (MAROUELLI et al., 2011).

Among the soil moisture-monitoring sensors, one can highlight the model HIDRO2 of Irrigas, which is manufactured by Hidrosense in Jundiaí (SP) - Brazil, presents low acquisition cost, easy reading, high-resistance and requires no periodic maintenance, providing thus great efficiency for several types of irrigation systems, as well as for potted plants (DOURADO et al., 2014; MAROUELLI et al., 2003). Several irrigation controllers associated to Irrigas sensors are found on the Brazilian market. Among them, MRI model controller, also manufactured by Hidrosense, is one of the best known and used for potted tomatoes. This device is set to measure and record average values of soil or substrate water tension, taken at each branch sensor (CALBO & SILVA, 2006).

The need for more complex and automated fertigation systems is greater for high market-value crops. The cherry tomato is one example of that since requires particular attention and, lately,

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it has been grown exclusively in protected environments, besides of receiving considerable investments in fertigation automation (CARON et al., 2013).

According to Pinto et al. (2013), for irrigation automation purposes, water consumption monitoring requires a system for collecting and processing data from the sensors according to criteria established by the users, besides having irrigation control devices. These authors also stated that commercial controllers are most of the time imported, with costs limited for most of the farmers and, as they vary with the type of water and nutritional management, e.g. cherry tomatoes, they are unable to meet the needs of most of the agricultural crops.

Given the above, the main purpose of this study was to developing a programming system and evaluating an automated control system for four fertigation management-types in an experiment with tomatoes of the cherry group, cultivar Sweet Grape, using a programmable logic controller and Irrigas sensors.

SUBJECT DESCRIPTION

Description of the experiment

The automation system was developed to control fertigations of potted cherry tomato 'Sweet Grape' cultivar, grown in coconut fiber substrate. The experiment was carried out inside a greenhouse with automatic temperature and relative humidity control. It was located in the experimental area of the School of Agronomy, Federal University of Goiás (UFG), Goiânia-GO (16° 35' S, 49° 16' W, and 722 m altitude), in Brazil. The greenhouse consisted of a single span with galvanized structure covered with polycarbonate panels, measuring 6 m width, 10 m length, and 3.2 m height, in the east-west direction. The greenhouse system was programmed to maintain an internal temperature around 25 °C and relative humidity near 65%, as recommendations for tomatoes made by MAROUELLI et al. (2011).

Seedlings of hybrid Mascot F1 plants, from cherry cultivar group 'Sweet Grape' cv., were planted in 8-L plastic containers. These pots were placed on metal benches, in order to be suspended, with a view to facilitating analysis and collection of drained solution for reuse. They were spaced 1.0 m apart between rows and 0.4 m between plants. One plant was cultivated per pot and stems were grown vertically on strings. The pots were filled with commercial substrate (Golden Mix, type 11, Amafibra), consisting solely of coconut fiber.

A completely randomized block design was used, with five replications. Treatments corresponded to four types of fertigation management, which were: Treatment 1 (T1) - reuse of 20% water leachate depth after each fertigation; Treatment 2 (T2) - fertigation and irrigation of 20% water leachate depth composed of pure water, applied only once at the end of the day; Treatment 3 (T3) - application of 20% water leachate composed of pure water at the beginning of each fertigation; Treatment 4 (T4) - fertigation reusing nutritive solution at the end of each fertigation by applying 20% water leachate depth, composed of the same solution. Since for tomatoes grown in the substrate, plant hydric and nutritional balances have to be monitored, on average, three to four times (MAROUELLI et al., 2003); fertigation was done in all applications.

Irrigation system

Irrigation was done by drip irrigation using self-compensating emitters, which were installed in polyethylene pipes with a nominal flow rate of 0.002 m³ h⁻¹. At the water outlet of these drippers, we installed microtubes, 0.5 m long, being attached to the pots by means of a plastic stake.

Pure water or nutrient solution irrigations were pumped using three independent motor-pump units connected by PVC pipes to three tanks. The pumps consisted of centrifugal pumps operating at 10 m.c.a and with a flow of 1.8 m³ h⁻¹. One tank stored pure water; the second was filled with a nutrient solution, and the third with reuse solution. At the outlets of each pump were installed PVC pipes. At the end of the tube delivering a nutrient solution, four solenoid valves were installed, as shown in Figure 1. At the first valve outlet, T1 branch was connected. At the second valve outlet,

part of the T2 branch was connected, being then plugged into the outlet of one of the two valves set in the pipeline delivering pure water. At the third valve outlet, part of the T4 branch was connected, which in turn was fitted to the other valve in the pure water pipeline. Lastly, at the fourth valve, the other part of T4 branch was connected, being joint to the valve outlet in the reuse tubing. This last assembly was made to ensure the plants were still being fertigated with nutrient solution, in the case of reuse solution ran out of the tank.

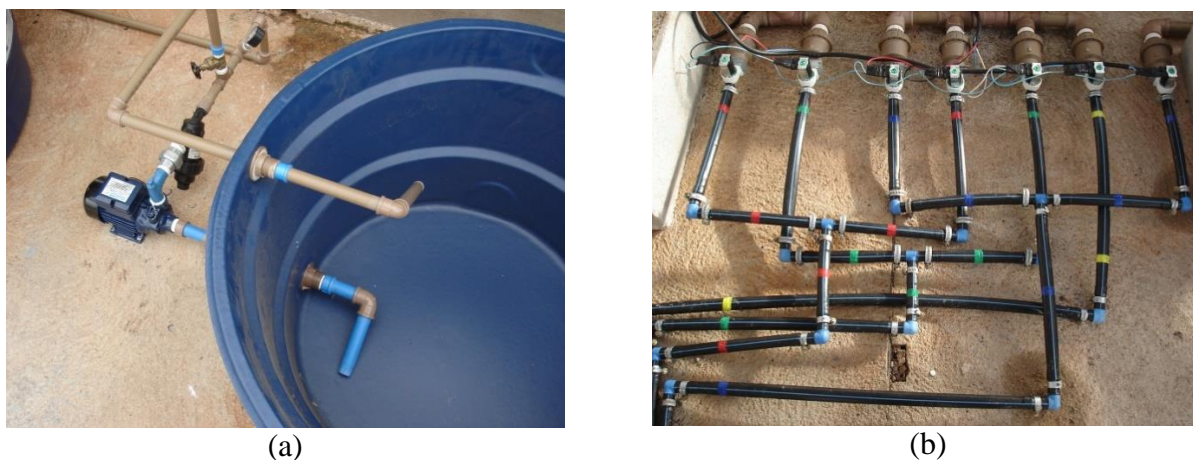


FIGURE 1. Motor-pump hydraulic fitting (a) and check and solenoid valves installed at the beginning of the irrigation line (b).

Substrate aeration (SA) had to be determined for estimation of the water volume to be irrigated. That parameter consists of the air volume within substrate after its saturation with water and total drainage at -1 kPa tension (De BOODT et al., 1972). We also estimated the content of readily available water (RAW), which for cherry tomatoes on coconut fiber is the one in balance with a tension of -3 kPa (De BOODT et al., 1972). Substrate total porosity (TP) was also determined. Our results showed SA of 23.55% (at -1 kPa), RAW of 35.18% (at -3 kPa), and TP of 86.79%.

Each fertigation duration varied with an average flow rate of the drippers, solution retention capacity by the substrate, and leaching amount proposed in each treatment. On average, four fertigations were performed daily with an average time of 30 minutes each. The need for leaching was determined according to the recommendations of SILVA et al. (2013).

Automation system development

Fertigation automatic control was made by an irrigation controller (model MRI, Hidrosense) associated to substrate moisture sensors, known as gas tensiometers or Irrigas, as well as to a programmable logic controller (PLC) with eight outputs. The Irrigas sensors were connected to the measuring center by microtubes and the remote reading of the sensors was carried out pneumatically.

Irrigation controller was equipped with four reading branches; each of them was connected to six sensors of water tension measurement set in the substrate. The reading of each branch was done remotely, in the measuring center, corresponding to the average of water tensions measured by each of the six sensors (CALBO & SILVA, 2006).

As endorsed by CALBO & SILVA (2006), one sensor was installed in each pot at an average depth of 0.15 m, equivalent to two-thirds of the pot height. Both horizontal distances between the plant and the sensor and between the dripping stake and the sensor were nearly 0.078 m. The irrigation controller was set to record and to store water tension data on substrate every three minutes.

Fertigation control was based on a daily irrigation management using a Hidrosense controller, which was set to trigger watering when tension reached -3.5 kPa, switching off the pump unit after

supplying the volume of water previously calculated based on substrate retention capacity and leaching requirement of each treatment. The PLC (WEG/ CLIC02 3rd) was used to switching valves and pumps (Figure 2).

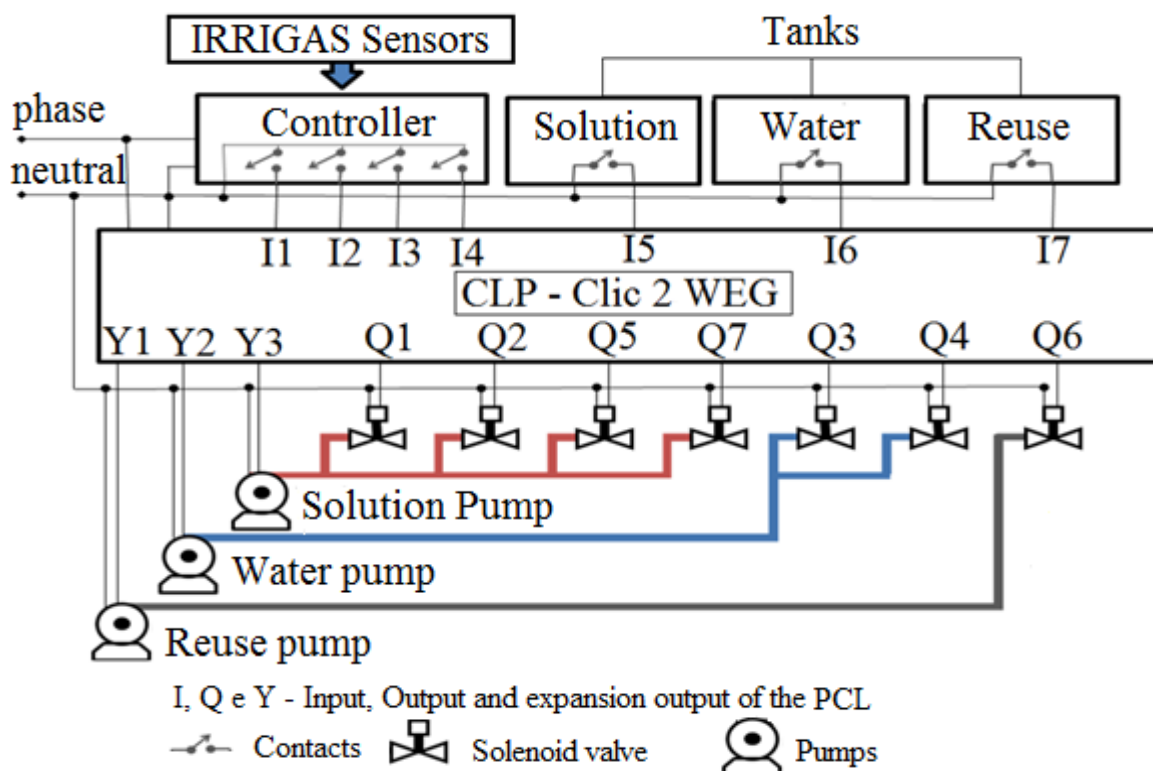


FIGURE 2. Diagram of the experimental control system.

Four fertigation strategies were set in the PCL, corresponding to each treatment, using a ladder programming language. This programming verifies the state of four PCL inputs triggered by the MRI irrigation controller (Figure 2) if substrate water tension reached one of the pre-set values. When receiving the command to initiate fertigation or leaching of salts, the corresponding solenoid valves and pumps were driven for intervals set by internal timers. The entire PCL programming could be attained by getting in contact with the authors.

Once programmed, at the beginning of the crop cycle, all fertigations are regulated by the system throughout the entire crop cycle, with no need for further human intervention.

Evaluations

The following evaluations were performed: A) system overall functioning by visual checking of water flow and nutrient solution closing and opening for each treatment; B) comparison of theoretical solution volumes with those actually applied in each treatment; to this end, both water and/ or nutrient solution volumes applied by drippers, as well as the amount of solution drained through the pot holes were measured and then correlated with the values calculated by PCL for each treatment; C) substrate moisture monitoring by means of tension records taken by PCL; to this end, the controller was programmed to record and store water tension data on substrate every three minutes; and D) comparison of the cost of system acquisition with other three national irrigation controllers and three international ones.

The aforementioned evaluations were carried out from May 30 to September 26, 2014, totaling 119 days.

RESULTS AND DISCUSSION

An initial simulation showed the automation system to perform pump-driving steps for the carrying out of PCL work routines, following the programming previously established. During this step, water flow or nutrient solution opening and closing followed what was set in each treatment, just as irrigation control was set by readings of sensors and substrate solution retention. It is noteworthy that cultivation substrates packed in containers require high instantaneous water needs per unit of root mass; however, it must be performed with strict control of irrigation, setting the volume and frequency of watering properly (OLIVEIRA et al., 2012; MAGÁN et al., 2008). Figure 3 shows the fertigation system in operation.



FIGURE 3. Fertigation system functioning.

Volumes applied to treatments 1 and 3 were 1.57% and 1.11% higher than was the theoretical value. Yet volume used in treatments 2 and 4 were 7% and 2.54% lower than was the theoretical one. Theoretical and actual volumes were close, thus validating the efficiency of the proposed system for both pre-established water and solution volumes, therefore, resulting in water and fertilizer savings.

Water tension range in the substrate remained on average between the limits set in this experiment (-3.0 kPa to 0.0 kPa) (Figure 4).

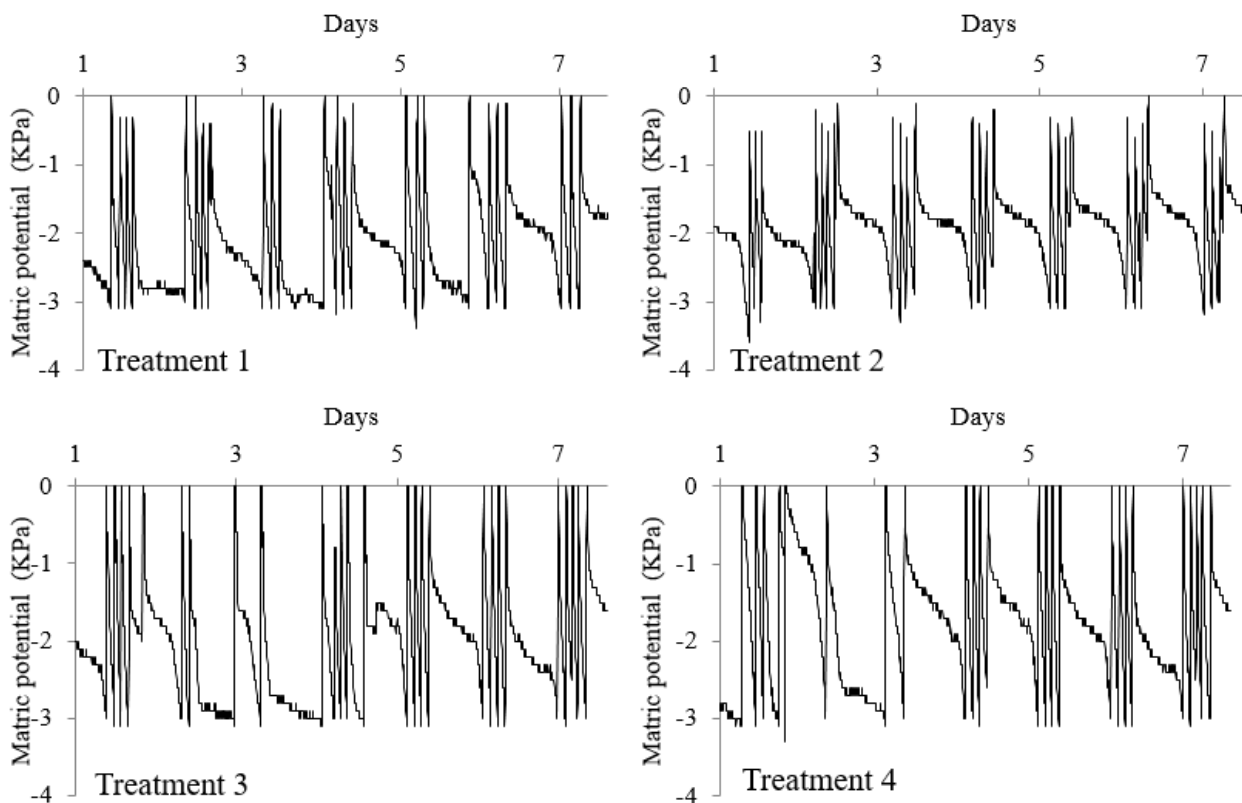


FIGURE 4. Matrix potential variation in the substrate over a week for the four treatments.

During the first days, substrate tension varied since the substrate structural was in adjustment until it reaches its physical stabilization. Tension values became most regular after 10 days of treatment application. After one week, water tension values in substrate had a similar behavior over time, when treatments were applied (Figure 4). This outcome points to a good functioning of the automation system, which ensured a uniform supply of water and nutrients to the plants over time. Crops grown under protected environment and on substrates, e.g. cherry tomatoes, have specific demands of water and nutrient levels to be added to the irrigated solution, and must be provided uniformly and in a well-balanced manner to increase productivity and to enhance quality of the harvested product (ABRAHÃO et al., 2014; VIEIRA, et al., 2014).

Figure 5 illustrates the daily variation in water tension of the treated substrates. In the analysis, different peaks of water tension are observed, which denote four fertigation in treatment 1 and five in the other treatments. Furthermore, one can note that the system was activated at the exact moment the substrate water potential, measured by sensors, reached -3.0 kPa. This value corresponds to the water potential set in the system to trigger irrigation. In short, the results show that the automation system had a good functioning, maintaining moisture in the substrate, besides providing satisfactory levels of nutrients for a good development of the plants. To achieve high productivity and to harvest fruit of good quality, substrate-grown tomatoes require an adequate supply of water and nutrients, under satisfactory conditions, throughout the day and during the production stage (THEBALDI, et al., 2013)

Water application at the end of the day, as in treatment 2, could also be noted by an increasing water potential recorded at 5:30 pm, after the last fertigation of the day (Figure 5). This value reached zero, what indicates that substrate had already been saturated by leaching application, which, in turn, could be visually proven through solution drainage under the pots.

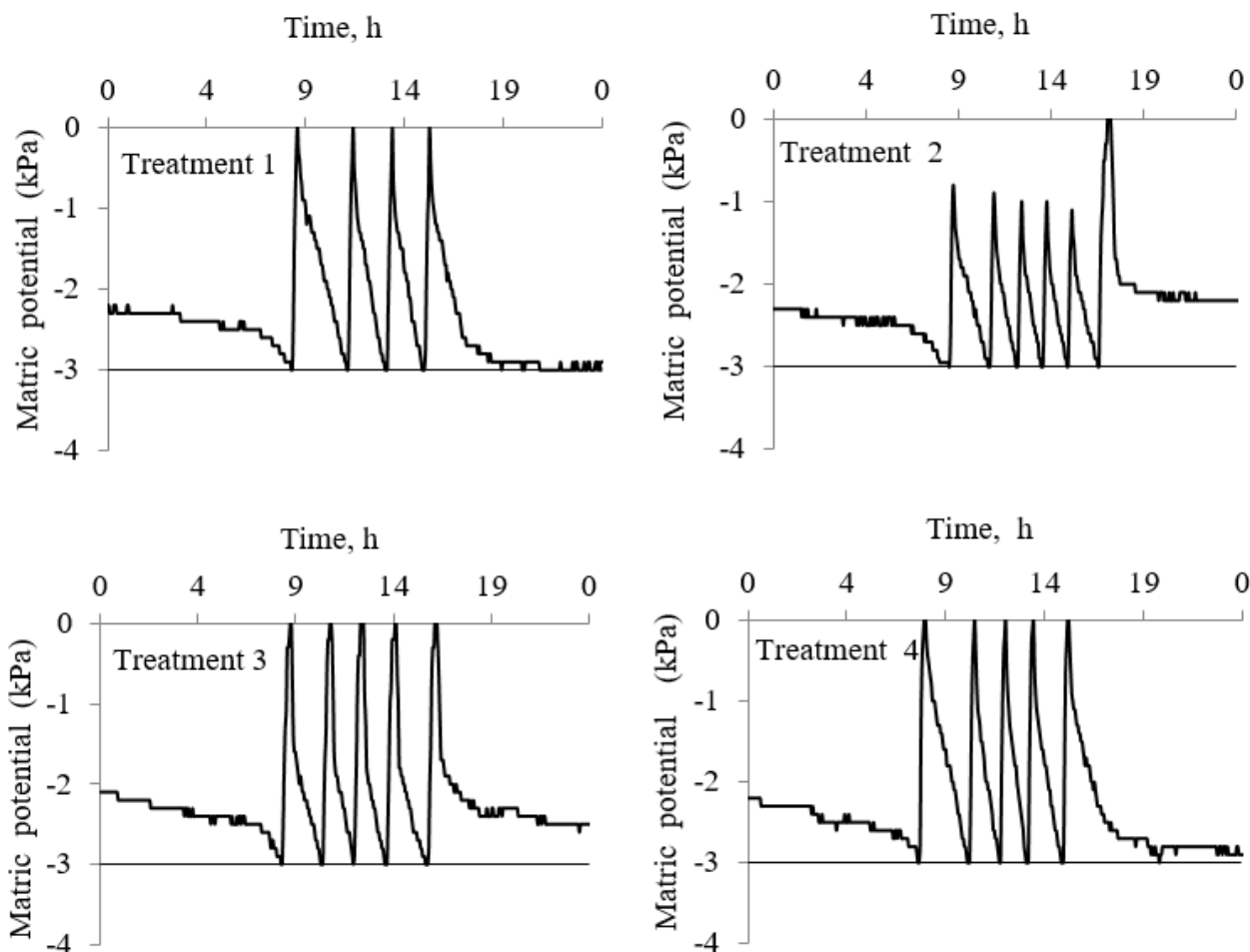


FIGURE 5. Variation of matrix potential in substrate throughout one day during for four treatments.

Substrate water tension remained constant and equal to zero for nearly twenty minutes during treatment 3 application (Figure 5). This outcome was already expected since with each irrigation activation, it was initially applied a water depth to promote salt leaching of substrate solution, and then a fertigation was performed. Moreover, water tension behavior was similar for treatments 1 and 4, once the amount of solution applied in both was practically the same, differing only in the concentration of salts (Figure 5).

As proposed by MAROUELLI et al. (2011), daily irrigations were spaced, on average, two hours apart (Figure 5), in order to meet instantaneous plant demands of water and nutrients. However, a visual difference observed for the lowest volume of water applied in treatment 2 might be due to the adopted management in which solution was applied during fertigations and, at the end of the day, a 20% leaching fraction was applied. Quite short intervals of irrigation may help maintain substrate moisture near its maximum capacity, which can also reduce the availability of oxygen to roots. On the other hand, major intervals between watering might increase saline concentration within the root zone, imposing water stress to the plants (SILVA et al., 2014)

The cost of acquiring an MRI controller (Hidrosense Ltd.) plus a programmable logic controller was of R\$ 7,341.00 (Table 1). It should be noted that such cost can be considered low if compared to the average prices of commercial controllers, which have an operating life and maintenance cost close to the equipment used here. When comparing the acquisition price of the controller used here with the average prices of national and imported controllers, which are regularly used in tomato cropping, we may note a difference of 30% and 123% respectively (Table 1). All of these controllers were able to control the same number of devices and could be programmed in a similar way.

TABLE 1. Costs of national and imported irrigation programmers.

Controller	Purchase cost (R\$)
MRI Hidrosense with 4 branches	6511.00
PCL Clic 2 Weg CLW-02/20HR-A	830.00
National controllers	9,564.00
Imported controllers	16,410.00

It is noteworthy that an MRI Hidrosense controller is marketed with one to six extensions. Thus, with due proportions in the demanded equipment, six irrigation, and fertigation strategies can be set using the proposed control system, or even have the control of six greenhouses using a single system. The controller with one single extension has a 45% lower cost and, with six extensions, this cost becomes 37% higher if compared to the controller with four extensions.

Another advantage of the developed fertigation automation system, compared to those routinely used by tomato farmers, as mentioned in Table 1, relies on its full system automation. Once it is programmed, at the beginning of the cycle, no further man intervention is required to trigger fertigations or application of leaching depths throughout the crop cycle. Since tomatoes produced in substrates require a suitable control of nutritional and water status, this proposed system could contribute to increasing crop productivity and quality of the harvested fruit.

CONCLUSIONS

The automation system developed here made an appropriate monitoring of fertigation, as well as made an effective application of the proposed leaching depths.

REFERENCES

- ABRAHÃO, C.; VILLAS BÔAS, R.L.; BULL, L.T. Relação K:Ca:Mg na solução nutritiva para a produção de minitomate cultivado em substrato. **Irriga**, Botucatu, v.19, n.2, p.214-224, abr./jun. 2014.
- CARON, C.C.; TESSMER, M.A.; MELLO S.C.; JACOMINO, A.P. Quality of mini tomatoes harvested at two maturity stages and kept chilled in three packages. **Horticultura Brasileira**, Brasília, DF, v.31, n.2, p.279-286, abr./jun. 2013.
- CALBO, A.G.; SILVA, W.L.C. Sistema gasoso de controle de irrigação: descrição e testes físicos para a avaliação de desempenho. **Bragantia**, Campinas, v.65, n.3, p.501-510, 2006.
- De BOODT, M.; VERDONCK, O.; CAPPAERT, I. Method for measuring the waterrelease curve of organic substrates. **Acta Horticulturae**, The Hague, v.37, n.1, p.2054-2062, 1974.
- DOURADO, L.G.A.; KOETZ, M.; BONFIM-SILVA, E.M.; SILVA, T.J.A., GUIMARÃES, S.L. Reposição de água na cultura da alface lisa com a utilização do irrigas em ambiente protegido. **Enciclopédia Biosfera**, Goiânia, v.10, n.18, p.2633-2646, jul./ago. 2014.
- MAGÁN, J.J.; GALLARDO, M.; THOMPSON, R.B.; LORENZO, P. Effects of salinity on fruit yield and quality of tomato grown in soil-less culture in greenhouses in Mediterranean climatic conditions. **Agricultural Water Management**, Amsterdam, v.95, n.1, p.1041-1055, set. 2008.
- MARQUELLI, W.A.; MEDEIROS, M.A.; SOUZA, R.F.; RESENDE, F.V. Produção de tomateiro orgânico irrigado por aspersão e gotejamento, em cultivo solteiro e consorciado com coentro. **Horticultura Brasileira**, Brasília, DF, v.29, n.3, p.429-434, jul./set. 2011.
- MARQUELLI, W.A.; CALBO, A.G.; CARRIJO, O.A. Viabilidade do uso de sensores do tipo Irrigas® para o manejo da irrigação de hortaliças cultivadas em substratos. **Horticultura Brasileira**, Brasília, DF, v.21, n.2, p.286, 2003.
- MELO JÚNIOR, J.C.F.; GERVÁSIO, E.S.; ARMINDO, R.A. Sistema de automação para o manejo da subirrigação em ambiente protegido. **Irriga**, Botucatu, v.18, n.2, p.337-350, abr./jun. 2013

OLIVEIRA, F.A.; OLIVEIRA, M.K.T.; SILVA, O.M.P.; MAIA, P.M.E.; PAIVA, E.P.; SILVA JÚNIOR, J.G. Desenvolvimento do maxixeiro cultivado em substrato fertirrigado com diferentes soluções nutritivas. **Revista Brasileira de Ciências Agrárias**, Recife, v.7, p.777-783, 2012. Suplemento.

PINTO, M. F.; SALVADOR, C.A.; CAMARGO, A.P.; ALVES, D.G.; BOTREL, T.A. Desempenho de lógicas de controle para o ajuste automático do pH da água utilizada em microirrigação. **Irriga**, Botucatu, v.18, n.4, p.708-720, out./dez. 2013.

SILVA, E.M.; LIMA, J.G.S.; DUARTE, S.N.; BARBOSA, F.S.; MASCHIO, R. Níveis de salinidade e manejo da fertirrigação sobre características da berinjela cultivada em ambiente protegido. **Revista Ciência Agronômica**, Fortaleza, v.44, n.1, p.150-158, jan./mar. 2013.

SILVA, M.C.; SILVA, T.J.A.; BONFIM-SILVA, E.M.; FARIAS, L.N. Características produtivas e qualitativas de melão rendilhado adubado com nitrogênio e potássio. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.18, n.6, p.581-587, jun. 2014.

SORENSEN, C.G.; FOUNTAS, S.; NASH E.; PESONEN, L.; BOCHTIS, D.; PEDERSEN, S.M.; BASSO, B.; BLACKMORE, S.B. Conceptual model of a future farm management information system. **Computers and Electronics in Agriculture**, New York, v.72, n.1, p.37-47, jun. 2010.

THEBALDI, M.S.; ROCHA, M.S.; SANDRI, D.; FELISBERTO, A.B. Características produtivas do tomate irrigado por diferentes sistemas de irrigação e qualidades de água. **Irriga**, Botucatu, v.18, n.1, p.43-58, jan./mar. 2013.

VIEIRA, G.H.S.; MANTOVANI, E.C.; SOARES, A.A.; MONTES, D.R.P.; CUNHA, F.F. Custo da irrigação do cafeeiro em diferentes tipos de equipamento e tamanhos de área. **Engenharia na Agricultura**, Viçosa, MG, v.19, p.53-61. 2011.

VIEIRA, D.A.P.; CARDOSO, K.C.R.; DOURADO, K.K.; CALIARI, M.; SOARES JÚNIOR, M.S. Qualidade física e química de mini-tomates Sweet Grape produzidos em cultivo orgânico e convencional. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, Pombal, v.9, n.3, p.100-108, jul./set. 2014.