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Vanessa De Fátima Grah
Instituto Federal Goiano

Fernando Campos Mendonça
University of São Paulo

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Development of a hydro-mechanical sequencer for automation of net-sprinkler irrigation

Vanessa de Fátima Grah*, Tarlei Arriel Botrel and Fernando Campos Mendonça

*Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Av. Pádua Dias, 11, 13418-900, Piracicaba, São Paulo, Brazil. *Author for correspondece. E-mail: vanessagrah@usp.br*

ABSTRACT. The automation of irrigation systems has been widely implemented in Brazil in recent years, which is necessary due to operational requirements, such as irrigation of large areas at night, and subdivision of the irrigated area because of restricted use of water sources. This study developed and evaluated a hydro-mechanical device for automatic sequencing of net-sprinkler systems. The prototypes were made and evaluated at the Laboratory of Hydraulics and Irrigation, Department of Biosystems Engineering (Esalq-University of São Paulo). It was assembled a net-sprinkler irrigation with four sprinklers with a sequencer prototype installed on each of them, consisting of a volume timer and a three-way valve with a trigger system. Tests indicated that the irrigation time per sprinkler were similar to those calculated for each timer. The system has proved to be a feasible alternative for automated, sequenced operation of sprinklers in a net-sprinkler system.

Keywords: automation, low cost, technological innovation.

Desenvolvimento de um sequenciador hidráulico-mecânico para automação de sistemas de irrigação por aspersão em malha

RESUMO. No Brasil, a automação de sistemas de irrigação vem sendo implantada com maior intensidade nos últimos anos, e se faz necessária devido necessidades operacionais, como irrigação de grandes áreas no período noturno e parcelamento da área irrigada oriunda da restrição do uso da água de mananciais. O trabalho teve por objetivo desenvolver e avaliar um dispositivo hidráulico-mecânico para sequenciamento automático da aspersão em malha. Os protótipos foram feitos e avaliados no Laboratório de Hidráulica e Irrigação do Departamento de Engenharia de Biossistemas (Esalq-Universidade de São Paulo). Foi montada uma malha de irrigação com quatro aspersores e em cada um foram instalados protótipos dos sequenciadores constituídos de um temporizador volumétrico e uma válvula multivias com sistema de gatilho. Realizaram-se testes de avaliação do sistema de sequenciamento, e observou-se que os tempos de irrigação por aspersor foram semelhantes aos tempos calculados para cada temporizador. Com isso, o sistema mostrou ser uma alternativa técnica viável para a automação sequenciada de aspersores em um sistema de aspersão em malha.

Palavras-chave: automação, baixo custo, inovação tecnológica.

Introduction

Currently, almost half of the world population depends on food which is grown using irrigation. The continued world population growth requires a competitive and technified agriculture that enables the production of high quality food at larger amounts, where irrigation is a great strategy to achieve this goal (OLIVEIRA FILHO et al., 2004). In the midst of increasing urban and environmental demands on water, agriculture must improve water use efficiency generally. With hotter temperatures and changing precipitation patterns, controlling water supplies and improving irrigation access and efficiency will become increasingly important (LYBBERT; SUMNER, 2012).

High costs of irrigation automation devices limit the growth of application of such technology by small scale farmers (MEDICI et al., 2010), mainly when there is concomitant falling prices of rural products and increase in production costs. To change that situation it is important to invest on the development of inexpensive devices to make these products more available to rural producers. According to Chhetri et al. (2012), innovation of technologies at the local level is crucial for enhancing adaptive capacity of farmers. There are many researches on irrigation systems, however small rural producers are unaware of the results or find difficulties of the implementation of their results. These difficulties occur due to environmental legislation barriers, which limit the expansion of irrigated areas, and because the costs for installation and maintenance are far from the Brazilian reality. Thereby, the development of low cost irrigation systems is of interest to small and medium farmers.

In this sense, net-sprinkler irrigation is an alternative for inexpensive irrigation systems. In net-systems, all pipes are interconnected, forming rings (PORTO, 2006). Therewith, water that reaches the sprinkler come from two pipes, reducing the flow by half at each pipe, which allows implementing lateral lines of smaller diameter, when compared to other sprinkler systems (Figure 1). Furthermore, in this system is used only one sprinkler by net, low to medium pressure, which reduces the necessity for pump power by unit area.

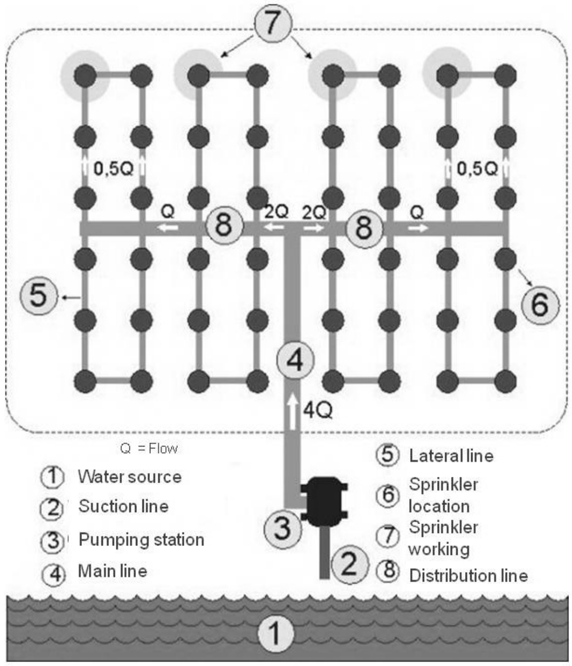

Figure 1. Net-sprinkler irrigation system (source: APRENDA FÁCIL EDITORA, 2010).

This characteristic has benefits, such as reduced installation costs, however it also generate problems related to the increased manpower. Farmer needs more time to manage the system given the change of sprinkler position in the area, which hinders irrigation at night. Hence, automation of net-sprinkler irrigation systems can meet the needs of rural producers, raising the productivity of the field work and increasing the advantages of nighttime irrigation in some regions, because of the lower costs of electric power at night.

Nevertheless, net-system automation is more complex because the water of sprinklers comes from two pipes of different ways, which requires the development of a specific automation. Low cost at the installation and maintenance are some features of net-sprinkler irrigation, thus, it is not interesting the use of eletronic components for its automation. In this way, the use of an automation system that does not use eletric power could make feasible the practice in the net-sprinkler system.

In this context, this study developed and evaluated a hydro-mechanical device for automatic sequencing of net-sprinkler systems, PI 1.104.434-9 (BOTREL et al., 2012).

Material and methods

Prototypes of sequenced automated sprinklers were developed at the Laboratory of Hydraulic and Irrigation, Department of Biosystem Engineering, College of Agriculture Luiz de Queiroz, University of São Paulo (Esalq/University of São Paulo). Automation set refers to a hydro-mechanical drive system for automatic control of net-sprinkler irrigation systems, which consists of: hydraulic valves (HV), three-way valves (TW) and devices of sequenced drive at the three way valve.

Practical foundations of the project

To each rise pipe connected to a lateral line with sprinklers were installed two serial HV, normally open-type. To control the functioning of these HV, we designed a three-way valve to control the pressure at the VH head. To activate the TW plunger, we designed a device constituted of a float ball and a lever (Figure 2).

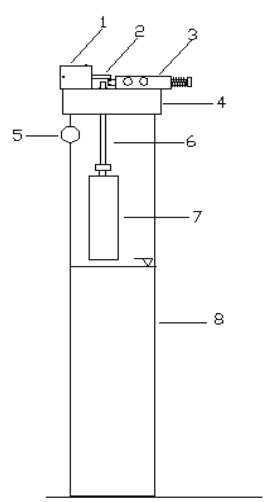

Figure 2. Lateral view of the automation set, with float ball and lever system for TW activation.

The float ball (7) is attached to the rod (6) and moves by buoyant force and after determined time, the rod (6) pushes lever (2) up, which is fixed to the support (1), and unlocks the plunger so that this shifts the position of TW (3), which is fixed to the base (4).

We connected a dripper (5) to the reservoir (8) to make the water level rise inside the timer reservoir (8) and consequently, move float ball (7) up. Dripper (5) and reservoir (8) work like a timer to control the irrigation time. According to the dripper (5) flow and reservoir diameter (8) used, it is possible to set different irrigation times.

Developing the three-way valve (TW)

After conception of the automation set project for sequencing of sprinklers, we started the construction of TW, which commands the HVs. In order to facilitate the understanding of TW operation, the names of inlet and outlet are given hereinafter: one water inlet (EA); one water outlet (SA1), which pressurizes the upper HV installed on the rise pipe of the next sprinkler; one water outlet (SA2), which pressurizes the lower HV installed on the rise pipe of the sprinkler where is the sequencing device; one air inlet (PA1), which allows that atmospheric pressure depressurize the upper HV of the next sprinkler, by opening it; one air inlet (PA2), which allows that atmosphere pressure depressurize the lower HV installed on rise pipe of the next sprinkler, wherein the set is, by opening it. Distances between orifices was named and given hereinafter (Figure 3).

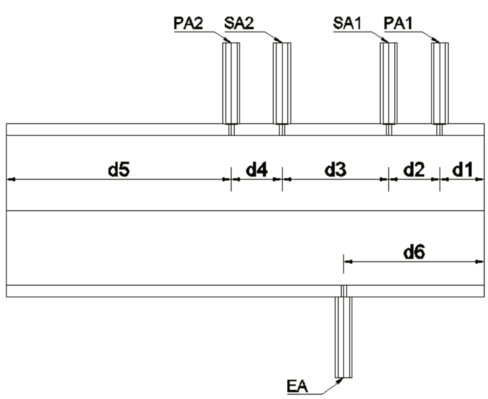

Figure 3. Lateral view of the TW structure of the automated sequencing set.

The three-way plunger (Figure 4) was made up of a rod with three protrusions for fitting the rubber rings. Distances between the protrusions were calculated according to the size of rubber rings (T_a).

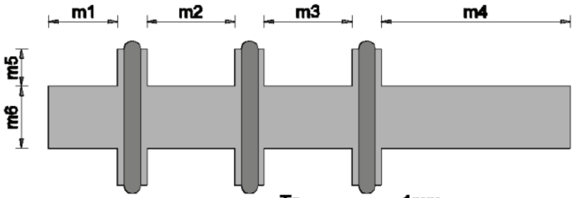

Figure 4. Lateral view of the TW plunger of the automated sequencing set.

The first three-way valve prototypes were made of PVC, due to its easy handling in the lathe. However, these prototypes showed leakage problems and high friction between the plastic pieces and rubber rings. High friction between the pieces hindered the instantaneous shift of the plunger, making impossible the exact time of ending the irrigation by sprinklers. For this reason new prototypes were constructed with brass. With the new material, leakage and friction problems were solved, obtaining a final TW with the following dimensions:

a) rubber rings: 2.68 mm internal diameter and 3.62 mm thick;

b) plunger: m_1 = 28 mm; m_2 = 11.7 mm; m_3 = 12.5 mm; m_4 = 30 mm; m_5 = 0; m_6 = 6.35 mm; groove diameter for fitting rubber rings = 4.8 mm.

c) body of valve: 70 mm length and 11.4 mm internal diameter; 1.0 mm diameter orifices for water and air inlet and outlet; d_1= 6.64 mm; d_2=7.2 mm; d_3 = 13.95 mm; d_4 = 5.8 mm; d_5 = 34.0 mm; d_6 = 20.8 mm.

Activation system of the three-way valve plunger

With the TW, we started the preparation of devices for plunger activation. There were made four prototypes until reaching the final result (not shown in this work). The first activation systems had a horizontal lever, with the float ball fastened at one end, and the TW plunger at the other end. Meantime, the tests showed that the system was inefficient and the plunger position shift occurred slowly, leading to imprecision in the irrigation time. Hence, we chose trigger system, which made instantaneous shift of position, as observed in Figure 5.

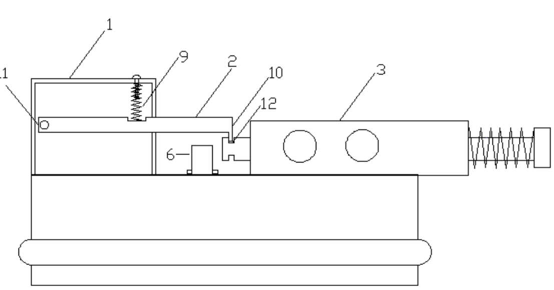

Figure 5. Trigger system for TW activation.

The trigger system for TW activation (3) is formed by a lever (2) with 61 mm length and 5.8 mm diameter. At one end, it was made a lock (10) and at the other end, the fulcrum (11). The valve was positioned (3) on horizontal at such a distance that the lever (2) was fitted in the plunger groove (12). When the float ball reached a determined level, the rod (6) of the float ball pushed the lever (2), triggering the shift of position. It was made a groove (12) with 4 mm thick at a distance of 20 mm from the closest rubber ring. A spring (9) was placed between the lever (2) and upper support (1), to facilitate return of the lever when trigger disarmed. Besides the aforementioned prototype, more three models were constructed to operate four automated sets, one for each sprinkler used in laboratory tests. In the manufacture of the levers, changes were made at the end of the rod holding the plunger in order to test the format with better performance when the trigger was disarmed (Figure 6).

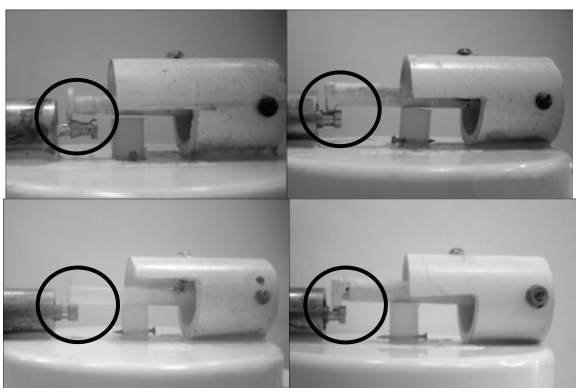

Figure 6. Formats of the lever end that hold the TW plunger.

Timer

After developing the prototypes of valves and their activation systems, we started making the timer (Figure 7).

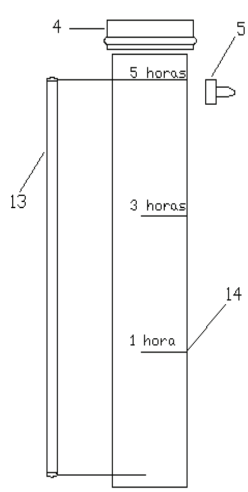

Figure 7. Timer with the components.

For this, we used a tube with 100 mm diameter and 850 mm length; at the bottom we used a silicon sealed PVC cap (4). A transparent microtube (13) was connected along the tube for checking the water level within the timer, forming communicating channels; the transparent microtube and the timer had the same water level. We put up on the top of the tube a self-compensating dripper (5) of 2 L h^{-1} that controled the irrigation time by flow. It is important to note that the timer of rigid PVC has good durability, but requires care when handling it in the field to prevent cracking. Timer operated as follows: one scale of irrigation times (14) was fixed adjacent to the transparent microtube. For example, if the farmer wants one hour irrigation, he fills up the tube with water to the height indicated by the arrow corresponding to the desired time.

Application of hydro-mechanical activation system for net-sprinkler irrigation

Before starting the irrigation it is necessary that all sequencer are triggered, with the three way valve plunger in the initial position. Thereby, at the start of irrigation, only the first sprinkler is operating. The others remain closed, because each TW valve pressurizes the upper HV of the next sprinkler. It is also necessary that the timer has been filled to the height corresponding to the irrigation time.

The sequencing was designed so that only one sprinkler operates by time. Irrigation starts with the sprinkler 1 (15) and simultaneously the dripper (5) begins to fill the reservoir (19) of the respective timer (Figure 8a). At the end of irrigation time chosen (Figure 8b), the float ball rod pushes the lever and shifts the three way valve to the position 2. After the position shift, the HV (17) of the sprinkler 1 (15) is pressurized and the drip ceases. Consequently, the upper HV head (18) of the next sprinkler (16) is depressurized, initiating the irrigation of the sprinkler 2 (16) and the filling of timer reservoir (20) of the second sequencer. Then, the dripper (5) of the second sequencer fills the timer reservoir (20) to the level corresponding to the selected time, when the float ball rod pushes the lever and TW plunger is shifted to the position 2. Therewith, the lower HV of the sprinkler 2 (21) is pressurized and the drip ends, while the upper HV of the sprinkler 3 is depressurized, initiating the irrigation and the filling of the timer reservoir of the third sequencer. The sprinkler 3 works in the same way as the sprinkler 2. At the end of the irrigation time, the float ball rod activates the TW and shifts its position. Thus, the lower HV of the sprinkler 3 is pressurized and the drip ends, at the same time the upper HV of the sprinkler 4 is depressurized, initiating the irrigation and the filling of the timer reservoir of the fourth sequencer.

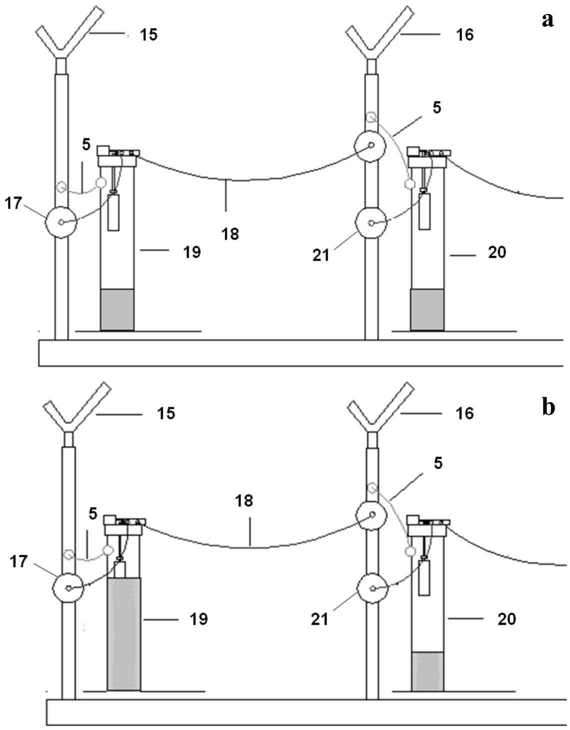

Figure 8. Start of irrigation with the first sprinkler (a). End of irrigation of the first sprinkler and start of the second sequencer (b).

This process can be performed for as many sprinklers as necessary, but to facilitate the tests, we made the sequencing for only four sprinklers. When the last sequencer starts its operation, the dripper starts to fill the timer reservoir until the moment the float ball rod activates the trigger and the plunger makes the position shift. When the lower HV of the fourth sprinkler is pressurized and the timer ends, irrigation is ceased.

As described, the sequencing system to exchange irrigated sector, was automated with a hydraulic-mechanical timer that controls the irrigation by time. However, it is necessary highlight some activities that farmers needs to do for putting on the automation system working out. If irrigation sector occurs all days, before to initiate the system the farmer must to go to each automation set and empty the timer reservoir until time scale corresponding to the time of irrigation. Furthermore, he needs to put TW plunger on position 1 and for that is enough push the plunger. These procedures done in each automation set, the irrigation sector can be initiated.

Evaluation of the automated activation system for sprinklers

With the whole activation system ready, we started the evaluation test of automated irrigation. We assembled a net-sprinkler system at the Irrigation Laboratory, with lateral line of 3 m length and tubes with 25 mm diameter (Figure 9). The water inlet for the dripper was installed at the rise pipe of sprinklers immediately above the upper HV and the water inlet of the TW valve was connected to the lower HV. To the rise pipe of the first sprinkler we installed a HV, and to rise pipes of others sprinklers we installed two HV. Sprinklers used were manufactured by Agropolo (NY25), with pressure between 245 to 343 KPa.

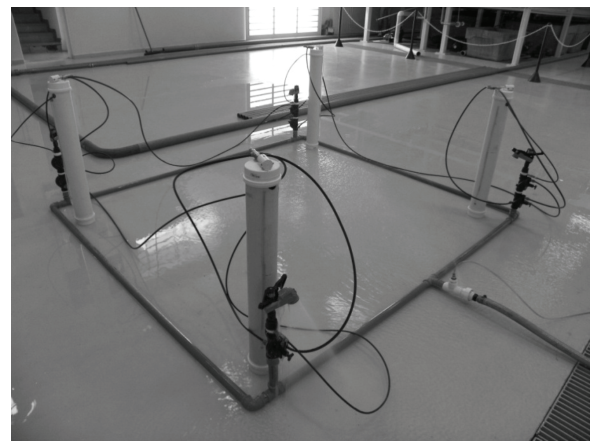

Figure 9. Net-sprinkler irrigation installed in laboratory with four sprinklers and four automation sets.

First tests were run for measuring the time necessary for the float ball to push lever and thus activate the plunger, considering zero as height reference in the time scale, from the underside of the float ball. To this end, with a measuring tape we measured the height from the upper side of the PVC cap until the lower side of the float ball, and marked this height in the transparent tube. When test began, the reservoir was already filled by water up to the mark “float ball”. With activation times measured, we determined the scale of the irrigation timer (T) subtracting 60 minutes by disarm timer (t).

$$T = 60 - t \quad (1)$$

where:

T is the time to complete one hour of irrigation (min.) and t is the time of activation of the trigger (min.). Then we calculated the volume (Vol) as follows:

$$Vol = T \times q \quad (2)$$

where:

Vol is the tube volume (representing the reservoir) corresponding to the time to complete one hour of irrigation (m^3), T is the time to time complete one hour of irrigation (h), and q is the dripper flow (m^3 h^{-1}). For the result of height (H) corresponding to one hour of irrigation, it make as follows:

$$H = \frac{Vol}{S} \quad (3)$$

where:

H is the height marked in the tube (m), and S is the tube area (m^2).

Besides checking the time required by the float ball to move the lever, we also verified possibles leakage in TW valves and microtubes. With the time scale, we performed tests for 1h and 1h 30 min. of irrigation, in which we confirmed whether the observed duration was the same as that calculated.

Results and discussion

The first tests aimed to measure the float ball disarm time, the zero time corresponded to the lower side of the same. We measured the heights of the float balls for each sequencer from the top face of the PVC cap to the underside of the float ball, and these heights were marked in timers. After this, we performed the tests, whose times are listed in Table 1. Note that in the first test, the irrigation time for the sprinkler 2 was longer compared to the others sprinklers due to leakage in the timer. After solving this problem, the second test was done.

Table 1. Irrigation time of the sprinkler considering the time zero as the lower side of the float ball.

	1st Test	2nd Test	3rd Test	4th Test
Timer 1	24 min. 42 s	27 min. 46 s	36 min. 37 s	28 min. 20 s
Timer 2	40 min. 27 s	30 min. 02 s	23 min. 58 s	26 min. 04 s
Timer 3	28 min. 10 s	24 min. 53 s	28 min. 41 s	30 min. 35 s
Timer 4	29 min. 18 s	34 min. 27 s	21 min. 14 s	28 min. 20 s

In the second test (Table 1), there was no leakage problems. However, in three valves the average time for shifting position was 30 seconds. To reduce this time, we made a new lubrication of plunger rubber rings (nautical lithium white grease), for reducing the friction. Next, the third test indicated no more problems with position shift. The fourth test was made to confirm the irrigation time, using the time measured at this test to calculate the time irrigation of 1h and 1h 30 min. for each timer.

In the fourth test, the sequencers showed similar times. The average value for this test was 28 min. 20 s and the greatest difference of time related to the average was 2 min. 16 s. These differences are probably due to the handmade nature of the prototypes and for this reason, they present inaccuracy in their dimensions. Another factor for this discrepancy was the use of different levers on each sequencer. This difference caused differences in the activation of triggers, which will be better explored afterwards, when we discuss about trigger systems and their performance. With the value of activation time, we calculated the time necessary to complete one hour of irrigation. We set one hour irrigation as the time in the scale, then we calculated the volume corresponding to the necessary time to complete one hour, using a dripper with flow of 2 L h^{-1}. Using a tube with 100 mm diameter and internal area of 0.00754296 m^2 we obtained the heights to write down in the corresponding timers (Table 2). Thereafter, the tests were done for one hour irrigation (Table 3).

Table 2. Results of calculations for making the time scales.

	Time	Volume (m^3)	Height (m)
Timer 1	31 min. 40 s	0.001056	0.14
Timer 2	33 min. 56 s	0.0011310	0.15
Timer 3	29 min. 25 s	0.000980	0.13
Timer 4	3 min. 40 s	0.001056	0.14

Table 3. Time observed for each sprinkler.

	5th Test	6th Test	7th Test	Sd*
Timer 1	51 min. 16 s	54 min. 05 s	65 min.	7 min. 21 s
Timer 2	50 min. 51 s	59 min. 47 s	55 min. 27 s	2 min. 39 s
Timer 3	59 min. 29 s	56 min. 36 s	57 min. 24 s	1 min. 12 s
Timer 4	49 min. 17 s	48 min. 17 s	49 min. 13 s	2 s

*Sd = standard deviation.

The time of one hour irrigation was evaluated for each sprinkler, which was repeated three times. The observed times were different from those calculated for one hour and sequencers also exhibited different times. As stated earlier, we made one lever model for each timer, which contributed to differences in time of activating the trigger between sequencers. The sequencer 1 had the worst performance and the highest standard deviation. Hence, this sequencer was discarded for future applications.

The sequencer 2 showed a good performance in terms of irrigation time, but during the tests this prototype presented more problems related to plunger position shift. Analyzing the times of the sequencer 3, irrigations times were satisfactory but the lever also demonstrated problems to activate the TW valve plunger. Also, the orifice made on the lever to serve as a foothold could not be larger than the screw, because in this case (prototype 3) there were problems with triggering. In this way, prototypes 2 and 3 were discarded for future applications. The sequencer of better performance with more constant irrigations time was the prototype 4 (Figure 10).

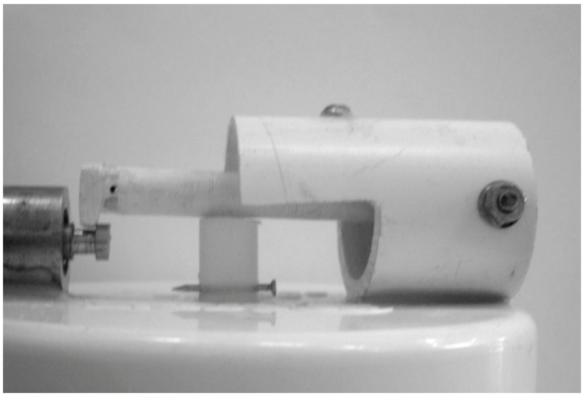

Figure 10. Prototype 4, with the best performance.

Despite showing irrigation time below that calculated, we recommend the prototype 4 for future applications. Nevertheless, the difference in the irrigation time observed may have occurred due to some mistake in marking the scale of irrigation at the timer. The prototype 4 had better performance due to the bevelled shape of the lever end that facilitated its displacement. Taking into account the mode of manufacturing prototypes, the performance of the automated sequencing is satisfactory for one hour of irrigation. However with prototypes being produced by specialized companies such flaws in the components will be reduced or even eliminated. Therewith, the difference of irrigation time between sequencers can decrease as well as time variations in each sequencer.

After tests of one hour irrigation by sprinkler, we carried out an irrigation test for one and a half hour to corroborate the idea that the timer can operate with any time of irrigation. Before starting, it was necessary to mark on the scale of each timer, the height corresponding to 1h 30 min. of irrigation (Figure 11).

Figure 11. Detail of timer scale for one and half hour irrigation.

Time for each sprinkler irrigation was as follows: sequencer 1 = 1h 38 min.; sequencer 2 = 1h 29 min.; sequencer 3 = 1h 25 min. e sequencer 4 = 1h 34 min. The observed times were close to the calculated times, showing a maximum difference of 8 min, in other words, 8.89% of the time calculated. But as stated earlier, due to the mode of manufacturing the sequencers showed a satisfactory performance during the test for one and a half hour irrigation.

Conclusion

After tests with prototypes, it can be concluded that the sequencing system is a viable technical alternative for automated net-sprinkler irrigation. During tests, the irrigation times observed for each sprinkler evidence that timer has a satisfactory performance. For future applications, the prototype with better performance that could be manufactured in commercial scale is the sequencer four.

Besides net-sprinkler irrigation, the sequencer can be used in other irrigation systems for meeting needs different from those suggested in this study. Microirrigation systems (drip or micro sprinkler) are usually divided into sectors, and thus could be potential guests to this type of automation, mainly small farmers who do not have capital to invest in expensive irrigation systems. The sequencing would work in the same way the only difference is that hydraulic valves must be installed at the beginning of the sectors. This proposed sequencing system is also indicated to conventional sprinkler systems, which are divided into sectors due to scarce water resources or to reduce the power of the pump.

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