HYDRAULIC DESIGN AND SIMULATION OF DIFFERENT COMBINATIONS OF BLOCKS OPERATING IN DRIP AND MICRO SPRINKLER IRRIGATION

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1 ABSTRACT

Farmers employing trickle irrigation frequently need to change irrigation block operations over the years (parcel combinations), because of plant renovations in certain areas of the irrigated field or the adoption of precision irrigation. It is worth emphasizing the importance of this software for the pre-sizing of localized irrigation systems. This work shows free software developed using Visual Basic® language that is able to simulate different block combinations of parcels, taking into consideration the pump parameters of flowrate, pressure, power requirements and efficiency and the main hydraulic network parameters of water speed, pressure and head loss. The software we developed was applied to a trickle irrigation system for citrus growing. The equations used to calculate head loss were Hazen-Williams and Darcy-Weisbach, and users could choose between these two equations depending on their application. The software worked efficiently for making the hydraulic calculations, providing simulations that graphically assisted users in choosing which combination of operation parcels (block combinations) and pump parameters (rotation speed and impeller diameter) for optimal operation of the irrigation system. The program ensured that the pressure along the irrigation network was compatible with the nominal operating pressure of the pipeline and safety valves.

Keywords: Drip irrigation, software, irrigation system, irrigation project, pump parameters

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2 RESUMO

Agricultores que utilizam irrigação por gotejamento frequentemente precisam alterar a operação dos blocos de irrigação ao longo dos anos (combinação de parcelas), devido a procedimentos de renovação de plantas em determinadas áreas do campo irrigado ou à adoção de irrigação de precisão. Este trabalho tem como objetivo apresentar um software livre desenvolvido (linguagem Visual Basic®), capaz de simular diferentes combinações de blocos

de parcelas, considerando as implicações nos parâmetros da bomba (vazão, pressão, potência e eficiência) e nos principais parâmetros da rede hidráulica (velocidade da água, pressão e perda de carga). O software desenvolvido foi aplicado a um projeto de irrigação por gotejamento de citros. As equações usadas para calcular a perda de carga são Hazen-Williams e Darcy-Weisbach, de modo que os usuários podem escolher entre as duas equações para realizar os cálculos. O software foi eficiente nos cálculos hidráulicos, permitindo ao usuário, por meio de simulações, escolher qual combinação de parcelas de operação (combinação de blocos) e parâmetros de bomba (rotação e diâmetro do rotor) se ajustam melhor à operação do projeto de irrigação, garantindo que a pressão ao longo da rede de irrigação seja compatível com a pressão nominal da tubulação e válvulas de segurança.

3 INTRODUCTION

Agricultural irrigation is mainly responsible for the excess consumption of water in farming, but it is a necessary and effective technique for increasing food production, which can reach from one and a half to three times the production of a non-irrigated area. However, it is estimated that 55% of the water used for irrigation is lost before reaching the root zone of the crops because of low conduction efficiency (15%), distribution (15%) and application (25%) of the irrigation system (MEUS *et al.*, 2018). Thus, it is a good strategy to give preference to pressurized irrigation systems that use water more efficiently, such as localized irrigation (drip and micro-sprinkler) (MENDONÇA *et al.*, 2020) and center pivot systems (HADJI, GUERRAH, ATIA, 2021).

Localized irrigation has been the fastest growing method in the world in recent years in terms of percentage of irrigated area (LALEHZARI *et al.*, 2016; MENDONÇA *et al.*, 2020). In Brazil, there is a tendency for this growth to persist, because of conflicts between different users, water rights, environmental concerns, and fees for water use, in addition to greater credit subsidies for equipment acquisition and environmental licensing by administrative licensors (OLIVEIRA *et al.*, 2010). In this case, localized irrigation has

an advantage over other methods because of its higher theoretical efficiency of water application, ranging from 75% to 95% (VALE *et al.*, 2020) compared to 45% to 75% for surface irrigation, 60 % to 90% for sprinkling (ARAÚJO *et al.*, 2020) and 40% to 70% for irrigation by raising the water table level. Also, it usually requires less energy because localized irrigation operates at low pressure (1.0 to 3.5 kgf·cm^{-2}). However, localized irrigation systems normally require a large capital investment for implementation; but they offer the possibility of recouping that cost through lower operating costs over the years. To reduce costs most effectively, the system needs to be carefully designed, so that the interactions between the several variables are optimized for the most economical use (VALE *et al.*, 2020)

A localized irrigation project can have numerous combinations of types and characteristics of emitters associated with different pipeline layouts, different divisions of plots and sectors, types of materials used in the various pipes of the system, types and associations of motorcycle pumps, diversity in lateral lengths, and many other characteristics of the system components (TOLENTINO JUNIOR; SILVA, 2020). Thus, the success of the project hinges on human interpretation, which in turn depends on the intellectual capacity, experience, and

knowledge of the designer, and the tools and resources used to execute it in the best possible way (SAAD; MARIÑO, 2002; SOUZA *et al.*, 2011). Some crop plants, such as perennials, for example, involve different varieties associated with rootstocks, different spacing and ages, which require different amounts and times of application of water and fertilizers within the same area (BOSO *et al.*, 2021). This irrigated area may still suffer from the spatial variability of soils and the different irrigation depths required, because of its distinct physical-hydric characteristics (ARRAES; MIRANDA; DUARTE, 2019; SAITTA *et al.*, 2020, SANTANA JUNIOR *et al.*, 2020). Therefore, when there is a need to change the operating sectors (irrigated plot combinations) to improve the agricultural management of the irrigated area, the producer encounters a lack of project information and calculation tools that could provide support for accurate decision making at the field level (SCHMITZ; SCHUTZE; PETERSOHN, 2002).

Commercial software for trickle irrigation design: Irricad, Irripro, Wcad and Irrimaker, cost around US 7,000.00 for a lifetime license. These softwares require a training period of around 80 hours for an irrigation engineering to become familiar with the design tools of each one (GALVÃO *et al.*, 2020; SILVA; TOLENTINO JUNIOR, 2020). In view of the cost and difficulty of encountering a free and friendly to use software for localized irrigation systems that performs operating simulations at farm level, for irrigation systems already installed in the field, this work aimed to develop a computational tool in Visual Basic Applications (VBA) ® / Microsoft Excel® for dimensioning and simulating the combination and simultaneous operation of different irrigation plots.

The program simulates the outcomes of these combinations in terms of the parameters of flow, pressure, power and performance of the motor-pump

combination and in the parameters of water flowrate, pressure and head loss of the main and secondary hydraulic network. To verify its validity, the software was applied to designing a micro-sprinkler irrigation project with self-compensating emitters, for citrus cultivation, to determine the potential of the irrigation project for meeting the water needs of actual plants in an irrigated area.

4 MATERIALS AND METHODS

4.1 The software and considerations adopted

The software was programmed in seven individual spreadsheets in order to organize the information clearly : (i) initial spreadsheet; (ii) spreadsheet for calculating the required depth and the number of sectors, one for micro-sprinkling and the other for dripping; (iii) spreadsheet for defining the lay-out and assembly of operating units; (iv) hydraulic calculation; (v) selection of the motor-pump set; (vi) simulation of the project's operation; and (vii) database with useful information for sizing. The programming structure did not consider the dimensioning of the derivation and lateral lines, but only the main, secondary, and tertiary piping network of the system and the flow versus pressure parameters required for the motor-pump set **Figure 2 a**. The application accounted for the existence of pressure regulating valves at the beginning of each parcel, so that the simulations of the pumping operation did not alter the flow of the system's emitters. Pump efficiency was considered to be constant up to 20% of variation in motor rotation or in pump rotor diameter selected.
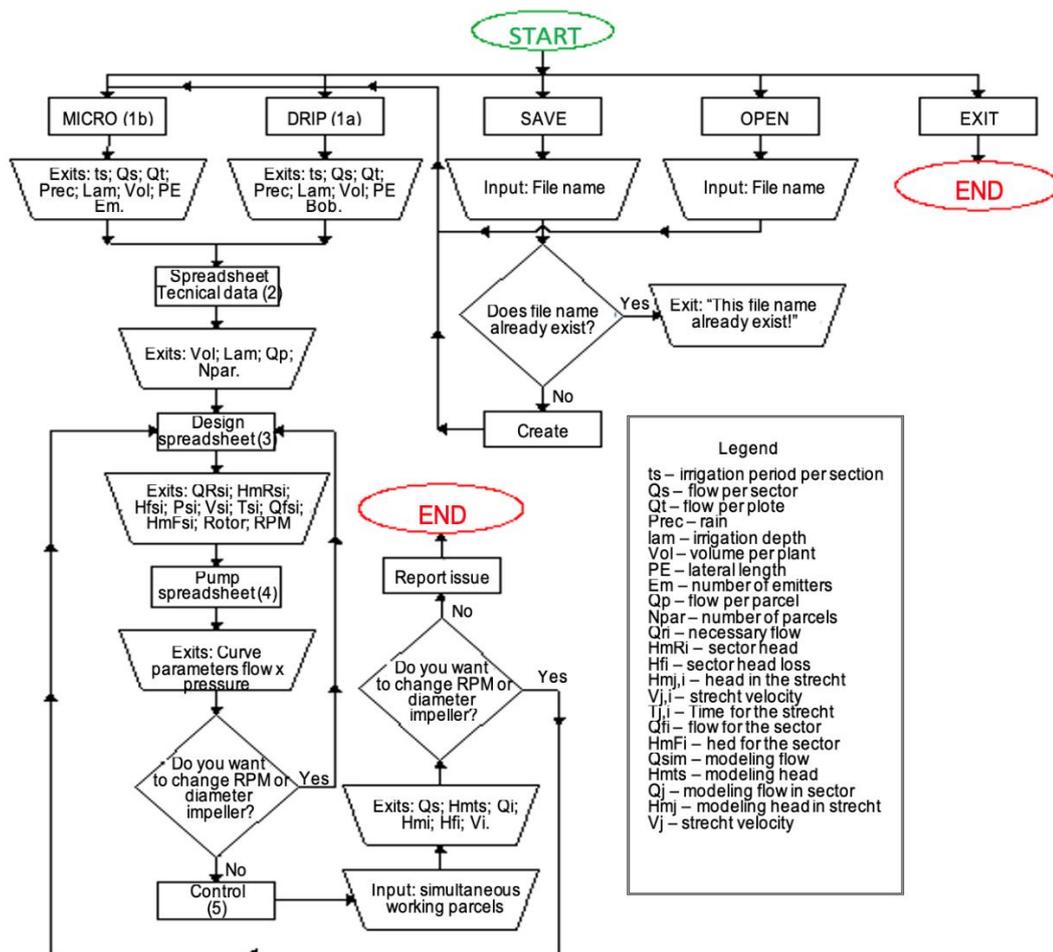
4.2 Description of the software

The computational model was developed with the objective of dimensioning an optimized localized

irrigation system. To perform the optimization, the model allows the user to design an irrigation system and execute operation simulations with different combinations of parameters associated with combinations of rotation and rotor diameter

of the motor-pump between the plots that operate simultaneously, to evaluate the behavior of the hydraulic mesh and determine the effect of the combinations. Figure 1 shows the application's general flowchart.

Figure 1. General flowchart of the application.

The inputs are represented by trapezius

For each irrigation method (micro-sprinkler or drip) there is a spreadsheet that allows the user to determine which emitter and which space between them provides the desired water depth depending on the spacing between plants, the number of sectors of operation, the efficiency of irrigation and the daily operating time. The layout is based on a plani-altimetric survey, alignment of the blocks and the emitter, division of plots, and layout of the pipe, but the user must still employ common sense

and experience to obtain a good layout. After the parcels are divided and the pipeline is drawn, the user must then perform the sectorization of the project, i.e, assembling the combinations of parcels that operate simultaneously and compose the irrigation sectors.

4.3 Hydraulic calculations

After the sectors are assembled, the 'sections' of the pipe must be numbered,

always starting from the motor-pump following the rules: (i) the motor-pump has a zero number; (ii) the first section connected to the motor-pump receives number one (1); (iii) the numbering in the sections must be continuous; (iv) the user must begin numbering with the sequence of stretches having the greatest number of nodes; (v) the numbers of the downstream sections must always be higher than the numbers of the upstream sections; (vi) the sections that derive from the same node must follow the previous rule; (vii) the numbers cannot be repeated; (viii) the spreadsheet is limited to 27 sections; and (ix) the 'interval' of the pipe is defined as the interval between two consecutive nodes.

The input data for each plot are the number of the section immediately before the inlet valve, the irrigated area, the spacing between plants and emitters, and the pressure required before the inlet valve. After filling in these data, the application provides the value of the applied depth (equation 1), the volume of water applied per plant (equation 2), and the flow of the plot (equation 3).

$$Lliq = \frac{q_i \; ts}{Ez \; el \; ef}$$
(1)

$$Vol = q_i \; ts$$
(2)

$$Qp = \frac{Ap \; q_i \; ts}{ez \; el}$$
(3)

Where Lliq is the applied liquid depth (mm·dia-1); qi is the flow per emitter (L·h-1); ts is the operating hours by sector; ez is the space between emitters on the line (m); el is the spacing between lateral lines (m); ef is the application efficiency (decimal); Vol is the volume applied per plant (L per plant·day-1); Qp is the flow per plot (m3·h-1); and Ap is the area per plot (m2).

In the next stage of the procedure, the hydraulic calculations of the project were carried out in the direction of the critical point (the one that requires greater head and flow) when pumping. To calculate the pressure loss along the pipes, the software allows the user to choose between the Hazen-Williams formula (equation 4) and the Darcy-Weisbach formula (equation 5) mentioned by Porto (2001) and Minhoni *et al.* (2020), respectively.

$$J = 10,646 \cdot \frac{1}{D^{4,87}} \cdot \left(\frac{Q}{C}\right)^{1,852}$$
(4)

Where: J is the head loss by unit of pipe length (m·m-1); D is the internal pipe diameter (m); Q is the flow (m3·s-1); and C is the coefficient that depends on the nature of the tube wall (material and conditions).

$$Hf = \frac{8 \cdot f \cdot Q^2 \cdot L}{\pi^2 \cdot g \cdot D^5}$$
(5)

Where: Hf is the head loss (m); f is the frictional coefficient (dimensionless); Q is the flow, (m3·h-1); L is the length of the pipe (m); g is the acceleration of gravity (9.81·m-2); and D is the internal pipe diameter (m).

With regarding to the localized pressure losses of the system (GOMES *et al.*, 2010; MESQUITA *et al.*, 2013), the application presents a specific cell where all localized pressure losses, including those of the suction and the discharge of the pumping, must be calculated. Afterwards, the data of the pipe (internal and external diameter and pressure class) and the topography (the difference in level between the nodes), and each 'stretch' (length) must be entered. After the data are entered, the application calculates the head losses, provides the pressure at the beginning and end of each section, and determines the flow

and pressure required for the motor-pump set. Based on the pressure and flow data, the user selects a pump model that meets the needs of the project. After pump selection, the rotor diameter and pump rotation are specified. Given the characteristic curves of the pump, the various flow points, the head, and the power absorbed from the original rotor diameter (largest diameter) are entered, after which the application calculates the pump efficiency (equation 10) and the motor power (equation 11).

Using equations 6-11, as described by Rosa e Emerick (2020) the application also calculates the new flow, the pressure, the power, and efficiency value, for any rotor diameter and any motor rotation, respectively (PINTO *et al.*, 2021).

$$Q_2 = \frac{Q_1}{\left[\left(\frac{RPM_1}{RPM_2}\right) \cdot \left(\frac{d_1}{d_2}\right)^3\right]} \tag{6}$$

$$Hmt_2 = \frac{Hmt_1}{\left[\left(\frac{RPM_1}{RPM_2}\right)^2 \cdot \left(\frac{d_1}{d_2}\right)^2\right]} \tag{7}$$

$$Pot_2 = \frac{Pot_1}{\left[\left(\frac{RPM_1}{RPM_2}\right)^3 \cdot \left(\frac{d_1}{d_2}\right)^5\right]} \tag{8}$$

Where: Q1 is the flow with the original rotor ($m^3 \cdot h^{-1}$); Q2 is the flow in the adjusted rotor (m3 · h-1); RPM1 is the original rotation; RPM2 is the changed rotation; d1 is the diameter of the original rotor (mm); d2- adjusted rotor diameter (mm); Hmt1 is the head in the original rotor (mca); Hmt2 is the head in the adjusted rotor (mca); Pot1 is the power in the original rotor (cv); and Pot2 is the power in the adjusted rotor (cv).

$$Potência = \frac{\gamma \cdot Q \cdot Hmt}{75 \cdot \eta} \tag{9}$$

Where: Q is the flow (m3·s-1); Hmt is the total manometric height (mca); η is the pump efficiency (decimal); γ is the specific weight of the liquid (kgf·m^{-3}); and T is the momentum (kgf m).

$$\eta = \frac{Q \cdot Hmt}{2,7 \cdot Pot} \tag{10}$$

$$T = \frac{Pot \cdot 736 \cdot 60}{2 \cdot \pi \cdot RPM} \tag{11}$$

These calculations are important for obtaining the best performance from the motor-pump set, especially in the case of a diesel engine. The program also allows simulations of associations of a maximum of two pumps in parallel or in series, with the same or different models.

4.4 Simulation of irrigation system function

The simulation of the functioning of the irrigation sectors is performed using the equation generated by a quadratic regression of the flow data versus pump pressure, adjusted graphically by Microsoft Excel®.

$$y = ax^2 + bx + c \tag{12}$$

Where y is the pressure, mca; a, b and c are the parameters of the quadratic polynomial curve; and x is the flow, $m^3 \cdot h^{-1}$.

As the equation of the pump curve generated by the regression is a function of the flow, the application finds the pump outlet pressure from the flow calculated for each simulated situation. It allows the diameter of the rotor or the rotation of the motor, or both (equations 6, 7 and 8) to be
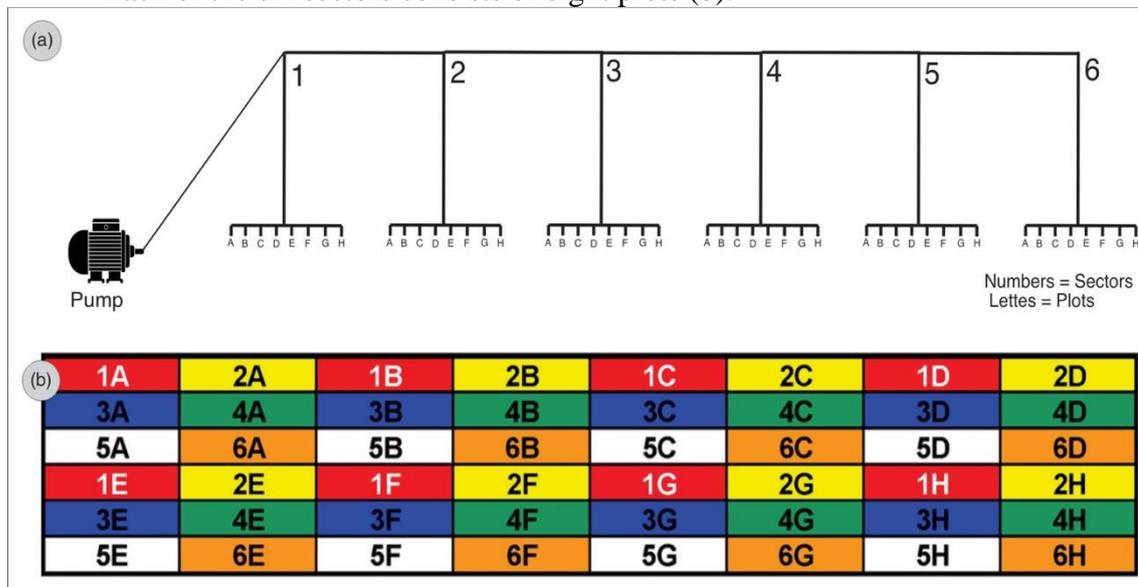
varied, so that the pressure values can be adjusted to the requirements of the system when a diesel power supply is used or a frequency inverter for an electric motor (PINTO *et al.*, 2021). In the next step, the values of parameters a, b and c, of the characteristic curve of the chosen and adjusted pump are used, so that the application calculates the motor-pump pressures in the pipe sections in the direction of the water path. The user can readjust the pumping rate or pressure, depending on the results obtained with the simulations. To run these simulations, the user chooses which plots he wants to operate simultaneously in the operating framework created by the application.

4.5 Characterization of the area used for the software application

The hypothetical irrigation system used to validate this work was installed in an area of 144.0 ha of citrus grove, with a rectangular shape (1,632 meters wide by 932 meters long) and 39.7 meters of difference in level, considering the level from the water surface at the catchment point to the highest point in the area. It was assumed that the area was planted with Cleopatra tangerine rootstock (Citrus reticulata, Blanco) and clove lemon (Citrus limonia, Osbeck), divided into four varieties of sweet orange (Citrus sinensis, (L) Osbeck).

The original irrigation project operated according to the combination of plots shown in Figure 2. Plots with the same number (same color) in Figure 2, are operated simultaneously, with each plot requiring a flow of 36.92 $m^3 \cdot h^{-1}$.

Figure 2. Schematic showing the distribution of the operating sectors and plots in the area (a). Each of the six sectors consists of eight plots (b).

5 RESULTS ANDDISCUSSION

5.1 Software characterization

The software starts from a home screen with the option to save a new file, open an existing file, exit the application, and choose between drip or micro-sprinkler irrigation systems. To dimension the localized irrigation system, the user must follow these steps: (i) define the number of irrigation sectors; (ii) define the irrigation layout; (iii) define the pipeline layout; (iv) dimension the hydraulic mesh; (v) select the motor-pump set; and (vi) optimize the operation. The definition of the number of sectors is done using data on the area, culture (type and spacing), climate (irrigation depth to be replaced), system (working hours) and emitter (space and flow) in the spreadsheet after choosing the system to be used. Depending on the irrigation depth determined for the project, the crop space, the daily working hours of the system, the emitter to be used in the project is selected and the number of irrigation sectors is defined.

The application starts from a determined irrigation depth instead of performing the calculations according to the physical-hydric parameters of the soil; this procedure aims to allow the user to choose the depth that best fits the variations of the area and the project. After entering the data in the spreadsheet for selecting the emitter and the number of operating sectors, the program calculates the precipitation (mm·h-1), the flow of the plots ($m^3 \cdot h^{-1}$), the average flow per sector ($m^3 \cdot h^{-1}$), the daily depth (mm), and the number of emitters (m for drip, and units for micro-sprinkler). The definition of the irrigation plots must include the divisions based on the plani-altimetric survey, what can be considered a limitation of the program. The characteristics of the selected emitter (which limits the maximum length of the lateral line), the topography of the land, and the crop and soil type. The

division should provide, as far as possible, a uniform flow between the irrigation sectors and a good coefficient of uniformity of water distribution. The number of plots in each irrigation sector must be entered. For example, in the project used in this work, there were eight plots for each of the six irrigation sectors, but the installment numbers by sector do not have to be the same. In order for the sectors to be assembled with the parcels already specified, the data entry table that will be used in this stage to define the layout will include area, spacing between lines, plants and emitters, and emitter flow. After entering the data, the software calculates the flow of each plot, the liquid depth and volume applied per plant, and assembles the project's operating table, in which the comparison between the flows of each irrigation sector can be performed. Normally, a tolerance coefficient of a 10% variation in flow between sectors is adopted (FARIA *et al.*, 2022).

The pipeline layout must be created according to the division of the areas (plots) and the characteristics of the emitters used, respecting the alignment of the plants to facilitate the assembly of the system. With the tracing performed, the user must design the 'internal' calculation of the plots, which includes dimensioning the lateral and derivation lines, as the necessary pressure and flow data at the entrance of each plot are important for the application. After this stage, the sections of pipe must be numbered and the number of the section immediately before the entry of a plot must be entered in the spreadsheet.
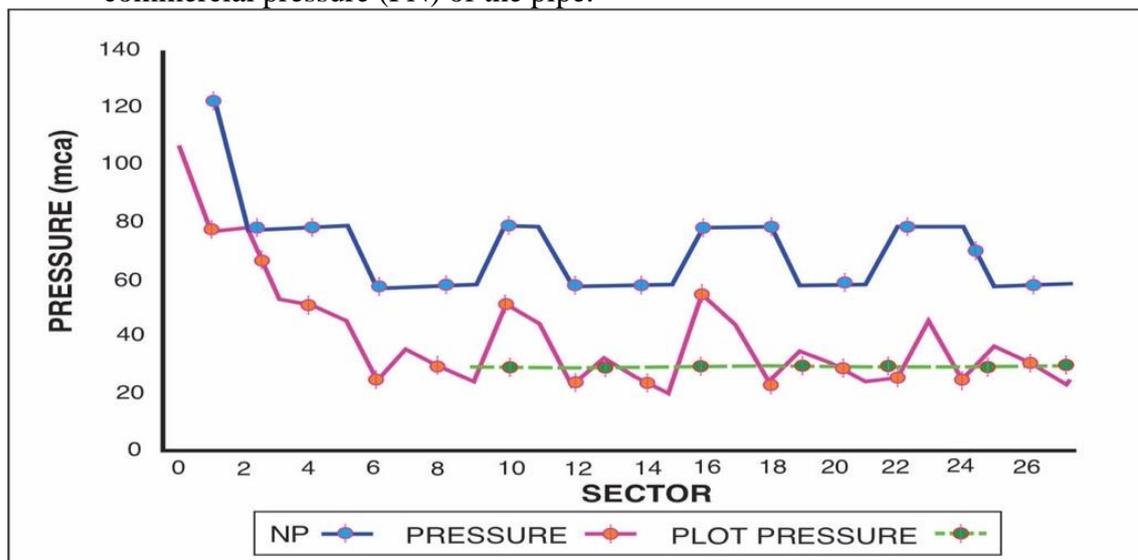
By entering the data about the system components (piping and special parts) and the altimetry of the area, the pressure losses of the system are calculated and the diameter and pressure class of the pipeline are dimensioned, from the critical point to the motorcycle-bomb. The input data are previous section, nominal diameter, pipe pressure class (PN), internal diameter, length

of stretch, difference in level between the beginning and end of the stretch, and friction coefficient for the Hazen-Williams formula or size of the pipe roughness for the Darcy-Weisbach equation. After entering the data, the application calculates the head losses and provides the working points of the motor-pump set for each sector of the irrigation system. From the flow and pressure data provided by the application, the motor-pump set is chosen from the catalogs of pump manufacturers that best fits the most demanding conditions of the irrigation project. With the pump selected, and using the characteristic curve provided by the manufacturer, the user selects and enters the ten sequences of pump flow, pressure and power data, rotor diameter (of the largest rotor) and original rotation, in the respective cells in the spreadsheet. From this data, the application calculates the pump efficiency and the power required by the engine and allows the calculation of new values by changing the set rotation and/or rotor diameter (PORTO, 2001).

If the user wishes to use a pump association, he must choose between the options "PARALLEL" or "SERIES". To do so, the user must provide the rotor diameters and the rotations of the desired sets in the tables called "PUMP 1" and "PUMP 2", and enter the parameters of the inverse pressure versus flow equation and the flow versus efficiency equation (SILVA *et al.*, 2020). From these equations, the application fills out the rest of the table with the flow, pressure, efficiency, and power data resulting from the association and provides the parameters for each of the equations. By entering the parameters of the pump characteristic curve, previously adjusted, the application then allows the user, to simulate the operation of the system in the direction of the water flow, due to the combination of functioning between the irrigation plots, providing fine adjustment of the hydraulic mesh (diameter and pressure class), according to the service pressure at each point in the network and in each irrigation sector. To do so, the user selects the portion he wants to operate by typing in capital "X" and pressing a button.

Figure 3. Comparison of the pressures of sections 1 and 2 of the system with the nominal commercial pressure (PN) of the pipe.

The final design of the pumping system consisted of two diesel motor-pump sets associated in parallel with the following characteristics: pumps with 385 mm impellers at 1800 rpm, a natural diesel engine with six cylinders, continuous power of 67.11 KW, momentum of 32.0 N·m and specific consumption of 162.0 g. (cv·h^{-1}) at 1800 rpm. Figure 4 shows the parameters of the motor-pump set for the original pump rotor (405 mm) at its nominal speed (1780 RPM). Figure 5 shows the same pump working at 1800 RPM with a 385 mm rotor diameter. Figure 6 shows the adopted options, consisting of an association of two pumps in parallel. The pumping system was correctly dimensioned and the diesel engine was within the optimum range for working speed, as it exhibited low specific consumption and the highest momentum (PORTO, 2001; PEREIRA *et al.*, 2020).

Figure 4. Adjustment of the parameter curves for the motor-pump set to parabolic functions with rotor diameter of 405 mm and 1780 rpm (original curves provided by the manufacturer).
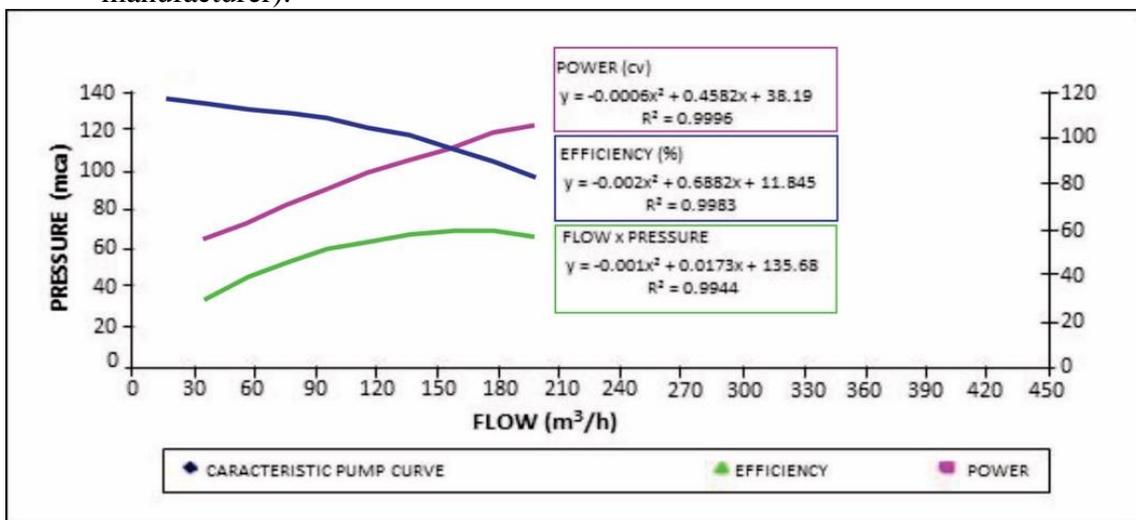

Figure 5. Adjustment of the parameter curves of the motor-pump set to parabolic functions with 385 mm rotor diameter and 1800 rpm rotation (best option for the project).
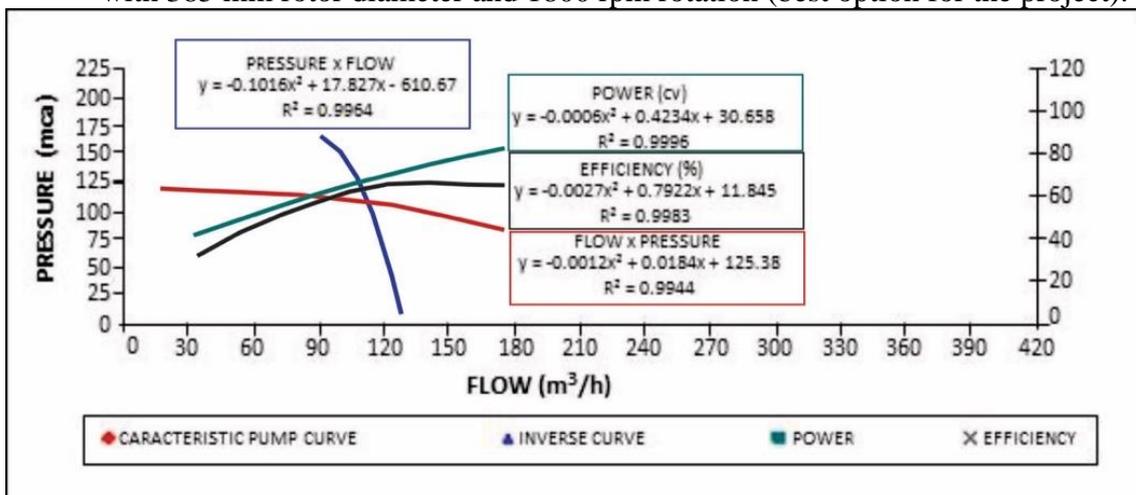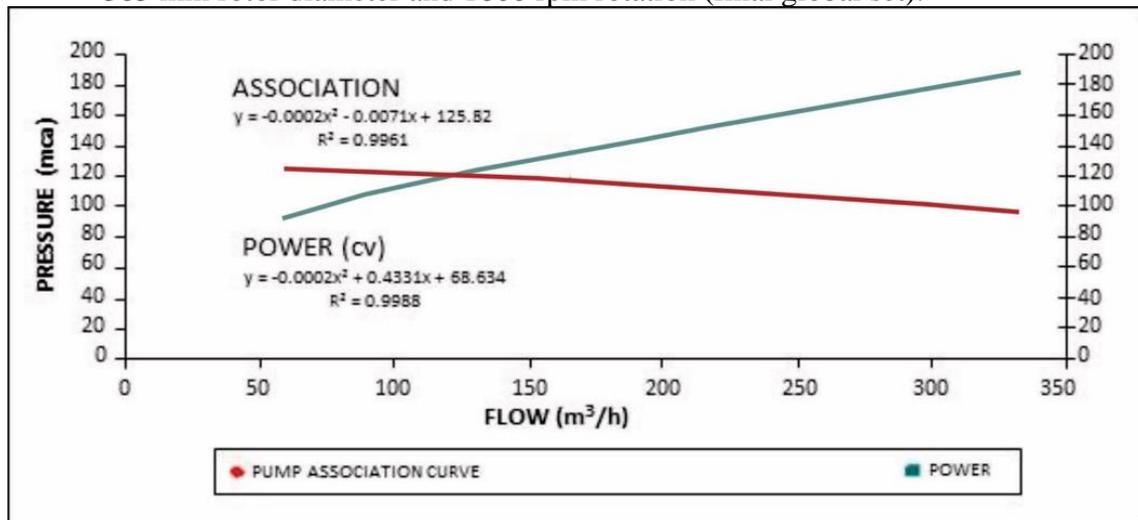
Figure 6. Pressure and power curves of the association in parallel with two motor-pump sets, 385 mm rotor diameter and 1800 rpm rotation (final global set).

6 CONCLUSIONS

a) Trickle irrigation farmers who frequently need to change their original irrigation block operation over the years (parcel combinations), because of plant renovation in certain areas of the irrigated field or for the adoption of precision irrigation techniques, can rely on the software developed here to use simulations of alternative trickle irrigation setups, to choose the combination of irrigated plots and sectors, pump rotation and rotor diameter, which best fits the original irrigation project, to ensure that the hydraulic pressure along the irrigation network for the new irrigation operation mode does not exceed the nominal pressure of the pipeline system.

b) The knowledge and experience of an irrigation designer is still necessary to define the best operational alternative for an irrigation project, however.

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