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TECHNIQUE CHARACTERIZATION AND HYDRAULIC PERFORMANCE OF PERFORATED HOSE SYSTEM FOR SUGARCANE IN COLOMBIA

CHRISTIAN JOSÉ MENDOZA[1]; JAVIER ALÍ CARBONELL[2] E JOHN JAIRO LASSO[3]

[1]Soil and Water Engineer, Agronomy Program, Colombian Sugarcane Research Center, San Antonio Experimental Station, Road Cali – Florida km 26, Candelaria, Valle del Cauca, Colombia, christianmendozac@gmail.com
[2]Ex-Director Agronomy Program, Colombian Sugarcane Research Center, San Antonio Experimental Station, Road Cali – Florida km 26, Candelaria, Valle del Cauca, Colombia, jjcarbonell@cenicana.org
[3]Agricultural Technician, Agronomy Program, Colombian Sugarcane Research Center, San Antonio Experimental Station, Road Cali – Florida km 26, Candelaria, Valle del Cauca, Colombia, jjlasso@cenicana.org

1 ABSTRACT

Sugarcane crops in Colombia are traditionally irrigated, and a higher portion of of the area with the irrigation system by furrows, where efficiency does not exceed 50% and present high application volumes per unit area. In pursuit of a more efficient use of water resources and conservation of the environment, a microirrigation system by perforated hose has been introduced recently. The objective of this research was to characterize and evaluate the performance of the perforated hose system. Therefore, to carry out this experiment, pressures 4, 5, 6, 7, and 8 PSI were evaluated, the flow in each orifice, and the water distribution in the system area. The following parameters were determined: (a) average flow rate, (b) coefficient of manufacture variation, (c) characteristic equation of the emitter/orifice, (d) distance between emitters, and (e) Christiansen Uniformity Coefficient-UC. The analyses showed coefficients of manufacture variation superior to 0.29 for all the pressures evaluated, and the UC were also very low for the system installation options in continuous furrow and alternate furrow, being superior to 43% and 52% respectively. The exponents x of the pressure versus flow equation will range from 0.119 to 0.813.

Keywords. Christiansen uniformity coefficient, coefficient of variation, characteristic equation.

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CARACTERIZAÇÃO TÉCNICA E DESEMPENHO HIDRÁULICO DO SISTEMA DE IRRIGAÇÃO POR MANGUEIRA PERFURADA PARA CANA-DE-AÇÚCAR NA COLÔMBIA

2 RESUMO

A cultura da cana-de-açúcar na Colômbia é irriga tradicionalmente e em maior porcentagem da área com o sistema de irrigação por sulcos, onde a eficiência não excede 50% e com altos volumes de aplicação por unidade de área. Em busca de um uso mais eficiente dos recursos hídricos e da conservação do meio ambiente, um sistema de microirrigação por mangueira perfurada foi introduzido recentemente. O objetivo desta pesquisa foi caracterizar e avaliar o desempenho do sistema por mangueira perfurada. Portanto, para realizar este experimento, se

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avaliaram as pressões de 4, 5, 6, 7 e 8 PSI, a vazão em cada orifício e a distribuição de água na área do sistema. Os seguintes parâmetros foram determinados: (a) vazão média, (b) coeficiente de variação de fabricação, (c) equação característica do emissor / orifício, (d) distância entre emissores e (e) Coeficiente de Uniformidade de Christiansen - CUC. As análises mostraram coeficientes de variação de fabricação superiores a 0,29 para todas as pressões avaliadas, também os CUC foram muito baixos para as opções de instalação do sistema em sulco contínuo e sulco alternado superiores a 43% e 52%, respectivamente. Os expoentes x da equação pressão versus fluxo variam de 0,119 a 0,813.

Palavras-chave: coeficiente de uniformidade de Christiansen, coeficiente de variação, equação característica.

3 INTRODUCTION

In sugarcane crops in the geographical valley of the Cauca river, several irrigation systems are used to supply the water needs of the crop. Among which is the irrigation by furrows, traditionally used and with the largest amount of irrigated area with this system, center pivot-linear sprinkler irrigation, and traveling gun. Also localized irrigation systems such as drip irrigation and, more recently, perforated hose irrigation. Localized irrigation is only the application of water in a timely manner and as close to the root zone. In this way, the objective of an irrigation system is to provide the water requirements that the plant needs in order to maximize production. The aim is to carry out this operation in the most efficient possible way, avoiding as much as possible the creation of large negative impacts on the environment.

The hydraulic operation of the perforated plastic hoses (PH) resembles orifice-type drippers. However, with the particularity that its outlet section increases with the pressure inside it depending on the elasticity of its wall. The PH can drip at very low pressures, however, if the pressure is less than 8 PSI, the droplets become small continuous jets (LOPEZ et al., 1992).

The emitters, devices designed to dissipate pressure, in microirrigation systems must present uniform and constant discharge, enough opening to avoid blockages, as well as low cost, robustness and homogeneity (FRIZZONE et al., 2012).

In the national market it is possible to find PH for the cultivation of sugarcane. It is made of low-density plastic material with virgin raw material to which micro-holes with metallic needles are made. They are the ones that distribute the water in very thin jets in spray form. It works with a maximum service pressure, according to the manufacturer of 8 PSI. Therefore, this study aimed to know the hydraulic performance and its technical characteristics of the operation.

4 MATERIALS AND METHODS

The experiment was carried out at the San Antonio Experimental Station of the Colombian Sugarcane Research Center (CENICANA). There was an adequate area (Figure 1) that had the appropriate and controlled conditions in the evaluations and the lesser interference of the climatic conditions on the irrigation system performance. Therefore, with the covered area the interferences caused by the wind which affect the distribution of the drops over the area of influence of the system were minimized and this also allowed to reduce the effects of radiation on the collected sheets of water avoiding the evaporation of them.

Figure 1. Adequacy of the area for carrying out the tests.

For the sheets collection, a collector (rain gauge) with a diameter of 7 cm and a volumetric capacity of 308 mL was available. It was made of transparent plastic to minimize evaporation of the sheet of water collected during the evaluation period.

For control and monitoring of the Input Pressure (IP) a glycerin pressure gauge with a capacity of 0 to 35 PSI installed in a ¾" PVC pipe was used in the PH. In the pipe a flow sensor was also installed for flow measurement, FS300A model with an approximate measuring capacity of 1 to 60 L/min, (Figure 2).

Figure 2. Device to control the IP and measure the flow.

The flow was recorded and stored with a reading device developed using an Arduino® Mega plate where the flow sensor was connected to record, every 5 seconds, the nominal flow and to record the volume applied by the irrigation system. The coefficient K of the sensor was calibrated for each of the pressures evaluated in the experiment.

The IP in each of the evaluations started at 8 PSI, pressure recommended by the manufacturer as service pressure of the PH and varying in 1 PSI to a minimum input pressure of 4 PSI totalizing 5 pressures evaluated. Each evaluation was done during one (1) hour in 6 repetitions and for a length of the PH of 10m.

The rain gauges were arranged in the area of influence of the PH and separated forming a grid of 33 cm between them, this value being a multiple of the separation between sides of 1.65 m. Commercial separation between rows in the sugarcane crop and where the lateral irrigation line is placed in the field. This separation value between the rain gauges allows the simulation of the uniformity coefficient to be carried out subsequently to the controlled evaluations with the two possible field arrangements being alternate furrow (AF) and continuous furrow (CF).

To determine the quality of irrigation there are some performance indicators such as uniformity, efficiency and degree of adaptation. From the technical point of view, uniformity measurements are the most used to know the behavior of an irrigation system.

Therefore, there are different coefficients to express the application uniformity of an irrigation system such as the Christiansen Uniformity Coefficient (CUC) and the Statistical Coefficient of Uniformity (SCU), among others.

To determine the uniformity of the microirrigation system by PH, the CUC proposed by Christiansen (1942) defined in ASAE Standard S.436.1 and given by the following equation was used.

$$CUC = \left(1 - \frac{\sum_{i=1}^{N}\left|X_i - \bar{X}\right|}{N \cdot \bar{X}}\right) \cdot 100 \qquad (1)$$

Where:
CUC: Christiansen Uniformity Coefficient, %
N: Number of collectors
Xi: Sheet collected at point "i", mm
$\bar{X}$: mean sheet of all observations, mm

Wilcox and Swailes (1947) defined the coefficient as a statistical parameter in which the standard deviation intervenes as a measure of dispersion called Statistical Coefficient of Uniformity (SCU) for use in the evaluation of sprinkler irrigation systems. Bralts, Edward and Wu (1987) proposed a statistical approach for the evaluation of microirrigation systems considering that this approach results from a probabilistic combination of the factors that influence the flow variation of the emitters, such as hydraulic factors, processes of manufacture, plugging and grouping of the emitters.

$$SCU = 100 \cdot \left(1 - \frac{S_x}{\bar{X}}\right) = 100\left(1 - CV_q\right) \quad (2)$$

Where:
$\bar{X}$: mean sheet of water collected by the rain gauges
S_X: Standard deviation of sheet of water data
CVq: Coefficient of Variation of flow

An efficiency measure that allows evaluating the performance of a micro-irrigation system is the Emission Uniformity (EU). It determines how uniform the system is in each of the emitters in relation to the average of the values of the applied flows. EU is the parameter recommended by ASABE standard EP 458 (ASABE, 1999) for the evaluation of uniformity in microirrigation systems.

Like the DU for spraying, it is defined in such a way that it shows the variation of the application of water through the ratio between the minimum and average flow of the emitters. It is calculated by the following equation.

$$EU = \frac{q_{min}}{\bar{q}}; EU = \frac{\bar{q}_{25}}{\bar{q}} \quad (3)$$

Where:
q_{min}: is the minimum flow of the set of emitters evaluated
$\bar{q}$: average of the flows of the emitters evaluated
q_{25}: average of 25% of the lowest values of the flows of the emitters evaluated

In order to determine the values of EU and the Coefficient of Variation of the flow by effects of manufacture ($CVq_{(F)}$) the flow of all the orifices present in the length of the PH was collected during 1 minute and in 6 repetitions. In this way, the following equation was used for the calculation, and with its respective classification by ASABE standard EP405.1 (R2014), Design and Installation of Microirrigation Systems.

$$CVq_{(F)} = \frac{S_q}{\bar{q}} \quad (4)$$

Where:
$CVq_{(F)}$: is the variation of the flows by effects of manufacture
Sq: standard flow deviation of the holes
$\bar{q}$: average hole flow

Classification in relation to the coefficient of variation of the flow by effects of manufacture for emitting tubes. Where $CVq_{(F)}$ less than or equal to 0.1 as good uniformity, $CVq_{(F)}$ between 0.1 and 0.2 average uniformity and $CVq_{(F)}$ greater than 0.2 as marginal or unacceptable uniformity (ASABE, 2014)

In order to properly select a sprinkler, it is necessary that the intensity of application does not exceed the basic infiltration rate of the soil (BERNARDO, SOARES, and MONTOVANI 2009). In addition, some authors have defined what is the infiltration rate for different soils and their classification. According to Bernardo, Soares and Mantovani (2009), the soil can be classified according to its basic infiltration rate at: greater-than 30 mm/h (very high VIB), 15-30 mm/h (high VIB), 5-15 mm/h (medium VIB) and less-than 5mm/h (low VIB). In the same way Brouwer et al. (1988) made a classification: Sandy more than 30 mm/h, Sandy loam 20-30 mm/h, Loam 10-20 mm/h, Clay loam 5-10 mm/h, Clayey 1-5 mm/h.

5 RESULTS AND DISCUSSION

The general characteristics of the irrigation system were determined (Table 1), which allowed identifying the area of influence of the PH in application and distribution of water.

Table 1. Operation characteristics of the irrigation system by PH

CHARACTERISTICS	PH
Pressure Service (PSI)	3 – 8
Diameter (inches)	1 ½
Available length (m)	7500
Reach (m)	3,35
Micro jets height (m)	2,35
Emitters distance pattern (cm)	7

The calculation of the UC was done with a format in an Excel® sheet prepared to be able to process the data obtained in the field and the data simulating the provisions of the PH in alternate furrow (PHAF) and in continuous furrow (PHCF) that would be possible in the field.

Table 2 shows the different UC values resulting from the data obtained in the different evaluations carried out.

Table 2. CUC of the data obtained and simulated for PHAF and PHCF

Pressure (PSI)	Repetition	PH	CUC (%) PHCF	PHAF				
4	1	-47,7	-28,9	-21,1				
	2	-52,4	-26,3	-14,5				
	3	-34,9	-11,5	-6,5				
	4	-33,9	-13,8	-1,0	Average:	-36,9	-14,7	-6,6
	5	-26,1	-4,5	-3,7	S_L:	10,9	10,8	10,0
	6	-26,4	-3,1	7,2	CV_L:	29,6	73,6	151,9
5	1	-9,0	6,3	17,3				
	2	-13,8	10,7	13,1				
	3	14,4	27,5	38,7				
	4	0,02	17,8	22,6	Average:	-7,4	12,8	19,1
	5	-14,3	11,4	14,9	S_L:	12,8	8,8	10,7
	6	-21,5	3,0	8,0	CV_L:	173,9	68,6	56,2
6	1	-11,5	12,4	11,2				
	2	-11,7	8,6	18,2				
	3	7,3	23,6	25,2				
	4	-6,6	15,8	19,6	Average:	-4,3	16,7	20,1
	5	8,5	27,3	27,0	S_L:	9,6	7,3	5,6
	6	-11,7	12,4	19,4	CV_L:	224,6	43,5	27,9
7	1	-9,8	19,1	21,1				
	2	-17,7	3,8	10,0				
	3	-1,5	18,0	23,1				
	4	-2,3	13,7	24,7	Average:	-1,5	18,7	23,5
	5	11,8	30,7	31,8	S_L:	11,5	9,6	7,8
	6	10,8	27,1	30,4	CV_L:	786,6	51,3	33,2
8	1	15,3	40,4	31,4				
	2	2,9	27,5	21,7				
	3	11,6	31,1	32,7				
	4	1,4	21,8	24,3	Average:	6,3	25,7	26,2
	5	-0,2	14,6	21,5	S_L:	6,1	9,3	4,8
	6	6,6	18,9	25,6	CV_L:	97,8	36,2	18,4
Average	-8,8	11,8	16,5					
S_L	17,9	16,6	14,2					
CV_L	204,5	139,7	86,2					

It is important, with the results obtained, to highlight that along the PH in a furrow of 100m, average of the lengths of the rows for sugarcane in Colombia, it is possible to have variation in the pressures present in the irrigation lateral side. This implies that, if the pressure at the beginning of the lateral is the maximum allowed

(8PSI), pressures from 8 to at least 4 PSI will be present along the lateral side. In this way we could have a uniformity for irrigation by maximum continuous furrow of 40.4%, being possible to be the average of the CUC for the different pressures, 11.8%. Still, more if the work of Laperuta Neto et al. (2011), is considered where determining that the loss of distributed load in an irrigation line can be, on average, greater than 70% of the total load loss.

Table 3. Mean sheet (mS) and maximum sheet (maxS) values collected in the evaluations (PH) and those simulated for PHAF and PHCF

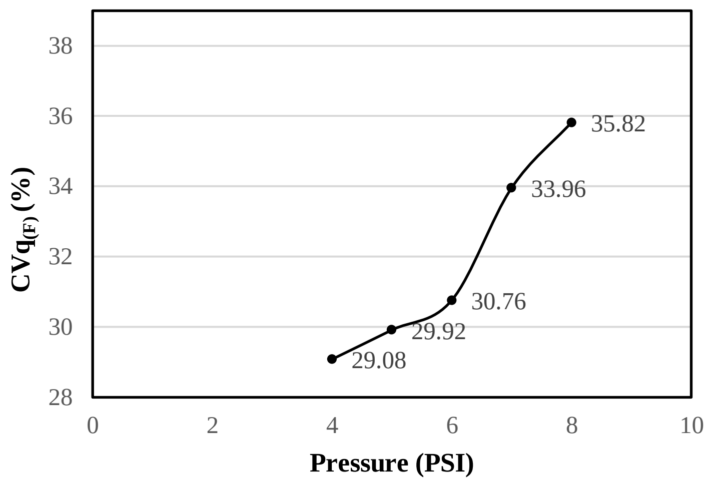
Pressure (PSI)	Repetition	PH		PHAF		PHCF	
		mS (mm/h)	maxS (mm/h)	mS (mm/h)	maxS (mm/h)	mS (mm/h)	maxS (mm/h)
4	1	4,0	57,4	7,9	58,7	13,0	222,8
	2	6,3	88,9	12,5	88,9	21,8	289,6
	3	6,0	47,3	12,6	61,1	19,8	190,6
	4	6,1	76,7	13,7	76,7	20,2	137,6
	5	6,8	71,5	13,5	72,5	23,2	200,2
	6	6,3	55,6	12,6	69,4	23,4	220,5
5	1	6,6	59,2	12,5	75,9	21,8	230,6
	2	7,7	53,3	13,6	65,0	24,6	144,0
	3	6,6	33,3	13,2	55,3	23,2	145,5
	4	8,0	73,5	16,1	94,3	29,3	321,2
	5	6,0	70,7	11,6	82,6	20,5	197,2
	6	6,9	61,1	14,9	107,1	25,7	258,1
6	1	7,5	63,7	15,0	67,6	27,5	161,0
	2	8,1	59,5	16,2	69,4	30,2	249,3
	3	7,4	35,6	13,4	47,6	24,4	126,5
	4	7,9	45,0	13,4	54,6	26,2	198,2
	5	5,7	39,2	11,5	46,3	20,3	92,3
	6	6,9	61,6	13,8	66,3	27,8	247,4
7	1	7,5	61,6	15,1	71,5	27,7	200,9
	2	7,4	103,4	14,8	132,5	27,7	238,8
	3	7,6	53,8	15,2	74,3	27,8	162,5
	4	7,7	59,0	15,3	77,2	29,2	246,7
	5	7,4	41,6	14,9	52,7	26,6	117,6
	6	6,6	38,5	13,2	44,2	24,9	132,2
8	1	7,8	57,4	15,6	67,3	26,7	102,3
	2	8,3	64,4	16,6	67,3	30,0	152,7
	3	8,5	46,8	16,9	52,0	30,6	163,4
	4	8,9	80,6	17,7	83,7	35,3	315,7
	5	7,1	53,0	14,2	60,3	25,0	151,1
	6	7,4	57,2	14,8	73,0	26,7	150,3
	Average	7,1	59,0	14,1	70,5	25,4	192,2
	S_L	1,0	15,7	1,9	18,5	4,3	60,8
	CV_L	14,0	26,6	13,8	26,2	16,9	31,6

In order to properly select a sprinkler, it is necessary that the intensity of application does not exceed the basic infiltration rate of the soil (BERNARDO et al., 2009). In addition, some authors have defined the rate of infiltration for different soils and their classification, according to Bernardo et al. (2009).

The values of the maxS under the PHCF configuration show maximum precipitation intensities from 92.3 to 321.2 mm/h, much higher than the infiltration rate for different types of soils, even for sandy soils with very high BIR, greater-than 30 mm/h. If we take as a parameter the arrangement of the alternate furrow system-PHAF, the lowest value of the maxS is 46.3 mm/h, also higher than the BIR for the soil with the highest infiltration capacity. It is important to note that the sheet values applied by the system are highly variable, with average values of 7.1, 14.1 and 25.4 mm/h for the PH, PHAF and PHCF configurations, respectively. In the same way, these values are verified and analyzed when calculating the coefficient of variation in relation to the collected sheet (CV_L), averaged for all the evaluated pressures presenting values higher than 13.8, for the maxS in PHAF, likewise excessively variable with a maximum of 31.6 for the maxS in PHCF.

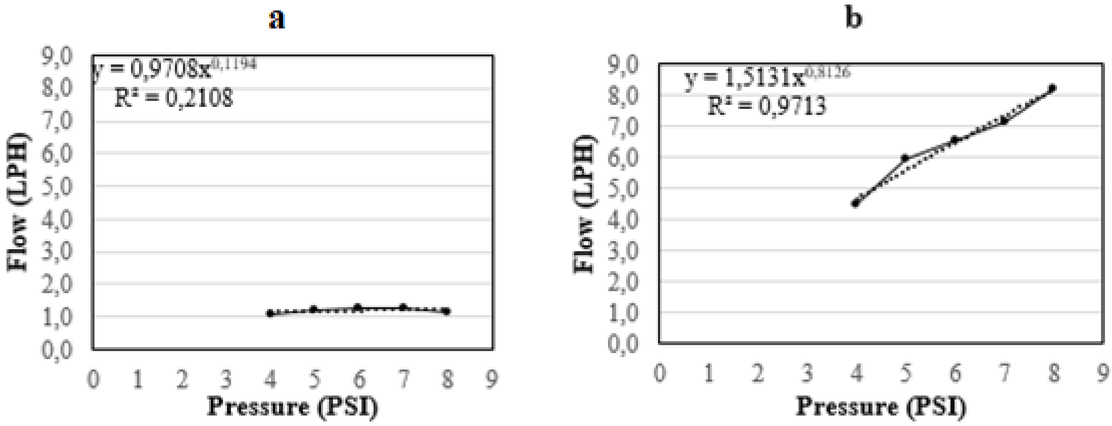
In order to better understand the behavior of the system in relation to the high variability of the applied sheet, the collection of the flow rate of each of the holes was made, which allowed to determine the coefficient of variation of flow through manufacturing effects-$CVq_{(F)}$. The value of the $CVq_{(F)}$ is shown in Figure 5, allowing us to observe that the variation of flow through hydraulic effects is well above the values recommended by the norm for microirrigation systems.

Figure 3. Coefficient of variation of the flow by manufacturing effects for the evaluated pressures.



As the variation of flow rate, in relation to the evaluated pressures, is very high, the characteristic curves of the flow-pressure ratio were generated for the minimum flows (Figure 4a) and maximum recorded flows (Figure 4b). The curve for minimum flows reflects what happens with the high variation that this irrigation system presents because it does not maintain a linear flow response as pressure increases. A situation that would be expected considering that the orifices have no system to compensate the pressure in which it provides a certain flow. However, these $CVq_{(F)}$ values are much higher than those found by Melo et al. (2017) where for one evaluated hoses, it was not more than 13% and for another evaluated hose not more than 25% within pressures of 4 to 8 psi, similar to those evaluated in this trial.

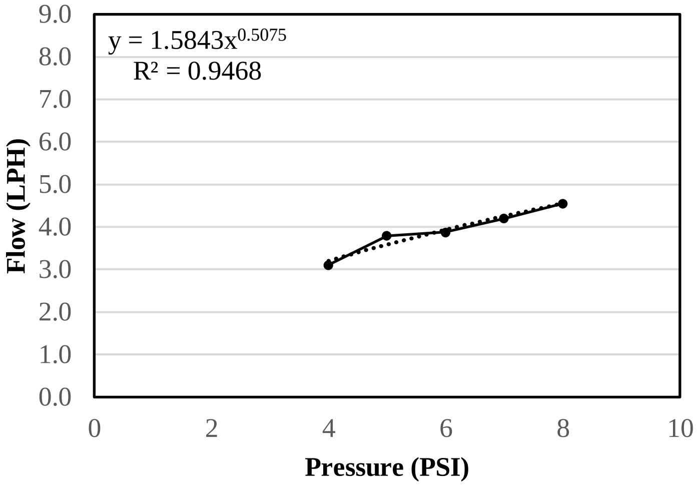
Figure 4. Characteristic curve of the flow-pressure ratio of the irrigation system by PH for minimum flow rates (a) and maximum flow rates (b).



With the curves of the flow-pressure ratio separated, depending on the flow rate applied by each orifice, the high variability of the flows is again evidenced by the effects of the manufacturing of the system. For the same pressure, 4 PSI, there may be flows from 1 LPH to 4 LPH, but although the lower flow rates remain very close to 1 LPH for all the pressures evaluated, the same does not happen when the pressures are increased, reaching higher flow rates to 8 LPH for the 8 PSI pressure recommended by the manufacturer.

For the mean flow data, the graph of the flow-pressure ratio (Figure 5) was also generated and the formula of the exponential form ($q = kH^X$) was obtained, where q represents the flow of a pair of holes (LPH); k is the coefficient of proportionality characteristic of the emitter; H is the pressure load (PSI); x flow exponent, so it is possible to know the influence of the pressure on the flow of an emitter. Therefore, for the average flow rates collected, the characteristic equation of the flow-pressure ratio is the following: $q = 1.477\ H^{0.5455}$ with $R^2 = 0.975$, therefore within the pressure band in which the equation is valid, the holes operate in a turbulent flow regime and their exponent is close to 0.5, as expected for emitters that operate in a turbulent flow regime (FRIZZONE et al., 2012).

Figure 5. Characteristic curve of the flow-pressure ratio of the irrigation system by PH for the average flow of the evaluations.



Investigations carried out on the hydraulic characteristics of a laser-perforated polyethylene tube will observe average coefficients of variation of 1.95, 3.31, 4.10 and 12.7% respectively, classifying the emitters from excellent to medium (ANDRADE, 1990; BONOMO et al., 1998; MARINHO et al., 1999; MELO et al., 2017). These values diverge a lot from those obtained in this work, the possible causes can be attributed to alterations in the material manufacturing process and aspects related to the maintenance, calibration and evaluation of the machines and equipment used in the manufacture of the hoses.

6 CONCLUSIONS

The CUC has shallow values, lower than those recommended for the sprinkler system, and even more for the microirrigation system, varying for PHCF between 3.0 to 40.4 and PHAF from 8 to 38.7%.

From the point of view of the coefficient of variation, the resulting values are very high, varying from 29.1 to 35.8% and affect the emission uniformity of the system. Therefore, these emitters are framed as unacceptable in terms of manufacturing uniformity according to the classification of the ASABE (2014) standard.

The maxS values under the PHCF configuration show maximum precipitation intensities of 92.3 to 321.2 mm/h and for the PHAF configuration between 44.2 and 132.5 mm/h, much higher than the infiltration rate for different types of soils.

The disposition of the emitters does not favor the distribution because it does not allow a more localized and uniform application of the water in the soil, presented in its Uniformity of Distribution very variable values even under the same pressure. All these are probable indications of improvements in the system both in the way of manufacturing and in the equipment used.

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