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DESEMPENHO DE SISTEMA DE IRRIGAÇÃO POR GOTEJAMENTO COM ENERGIA SOLAR FOTOVOLTAICA

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RESUMO: A verificação da uniformidade de aplicação de água em sistemas de irrigação localizada, constitui-se em uma ferramenta que promove o seu dimensionamento adequado, de maneira a resultar no melhor rendimento das culturas. Objetivou-se com este trabalho avaliar o desempenho, pelos coeficientes de uniformidade, de um sistema de irrigação por gotejamento, com diferentes comprimentos de linhas laterais, operando sob energia solar fotovoltaica. O trabalho constou do dimensionamento hidráulico para encontrar os comprimentos ideais de linhas laterais que possibilitassem menor variação de vazão por variações de pressões entre 5 e 15 mca, seguido dos testes de uniformidade CUC, CUD e CUE em duas situações (com e sem calibração da pressão do sistema no início da área em 10 mca). Conclui-se que ao se calibrar a pressão de serviço no início da área em 10 mca, em qualquer período do dia observado, a uniformidade de aplicação de água ficou acima de 90%, o que classifica o equipamento como excelente para os comprimentos de linha lateral de 30 a 60 metros.

Palavras-chave: Energia renovável, uniformidade de distribuição de água, economia de energia elétrica.

PERFORMANCE OF DRIP IRRIGATION SYSTEMS WITH SOLAR PHOTOVOLTAIC ENERGY

ABSTRACT: Verifying the uniformity of water application in localized irrigation systems is a tool that promotes proper dimensioning to achieve the best crop yield. The objective of this work was to evaluate the performance, through uniformity coefficients, of a dripping irrigation system with different lengths of lateral lines operating under photovoltaic solar energy. The work consisted of hydraulic dimensioning to find the ideal lengths of lateral lines that would allow less variation in flow due to pressure variations between 5 and 15 mca, followed by uniformity tests CUC, CUD and CUE in two situations (with and without system pressure calibration at the beginning of the area at 10 mca). When the service pressure at the beginning of the area at 10 mca was calibrated, at any time of the day observed, the uniformity of water application was above 90%, which classifies the equipment as excellent for line lengths ranging from 30 to 60 m.

Keywords: Renewable energy, water distribution uniformity, electricity savings.

1 INTRODUCTION

The use of solar energy as an energy source began in approximately 1876, with the first photovoltaic prospect built. However, it was only in 1956 that industrial production began in the sector, following the development of microelectronics. However, the use of solar energy as an alternative source of electrical energy began in 1959 in the United States, with the initial objective of using it as a generator of electrical energy for satellites (Marques; Krauter; Lima, 2009).

In Brazil, the use of photovoltaic solar energy was regulated through Normative Resolution No. 1,059, of February 7, 2023

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(ANEEL, 2023), whose equipment supply then intensified. One factor that initially makes it impossible for rural producers to acquire photovoltaic energy generation equipment is that the acquisition cost is relatively high for the vast majority of the Brazilian population; according to Bruning *et al.* (2023), photovoltaic energy generation projects for irrigation systems have increasing costs because of the increase in power.

The use of photovoltaic solar energy has been on a constant rise in Brazil and around the world, whose market niche, previously dominated by the Japanese, now stands out in Germany as its major global showcase for the expansion of this technology (Lana *et al.*, 2016).

Scientific research in the area of agricultural sciences has led to studies on this topic of renewable energy. Thus, even for the irrigation of crops intercropped with energy from a photovoltaic energy generation system, it appears that, for small areas, the system is satisfactory in that it provides sufficient flows and pressures to provide a germination rate. of up to 95% in mutual cultures, as well as being a system whose viability has been proven technically and financially (Fraidenraich; Bione; Vilela, 2006).

Understanding how an irrigation system can achieve ideal levels of water application uniformity via solar energy, with the recommendation of ideal lateral line lengths that provide greater application efficiency, is of fundamental importance for the sustainability of water resources, especially in semiarid regions.

Furthermore, in the absence of clouds and clear insolation, the daily period between 12 and 3 pm proves to be the hiatus of the day with the highest energy production from a photovoltaic energy generation system, taking into account that the net solar radiation in this interval presents the highest values in relation to other times of the day, as well as the first and fourth quarters, which are the times of the year in which the highest energy conversion rates are observed compared with the other quarterly verification windows (Silva; Vieira, 2016).

Another emphasis given when talking about irrigation using photovoltaic solar energy refers to the fact that the rural property that uses this technology becomes a sustainable enterprise, from an energy point of view. In view of this, as it does not use fossil fuels or conventional electrical energy, the most diverse electronic equipment can be used even in places where there is no electrical network, even devices necessary for the so-called Agriculture 4.0, such as robotic equipment, monitoring and activation via the internet and automation (Sant'anna *et al.*, 2021).

An important parameter for confirming the success of drip irrigation is the efficiency of water application. Therefore, there are several methodologies for checking the uniformity of water application in irrigation systems, including the Christiansen uniformity coefficient (CUC), the coefficient of uniformity of distribution (CUD), and the statistical uniformity coefficient (CUE). The joint observation of these coefficients is necessary to evaluate the performance of any irrigation system (Santos *et al.*, 2013). In drip irrigation with photovoltaic solar energy, excellent CUC and CUD values were observed under open-sky conditions (Zago *et al.*, 2022).

Owing to its high uniformity and ability to maintain continuous soil moisture close to the root system, drip irrigation has been the most commonly used method to the detriment of other irrigation systems, achieving uniformity values above 90% (Maia *et al.*, 2010).

The objective of this work was to evaluate the performance, through uniformity coefficients, of a drip irrigation system with different lengths of lateral lines operating under photovoltaic solar energy.

2 MATERIALS AND METHODS

The experiment was conducted in the area of the Federal Institute of Education, Science and Technology Baiano *Campus* Guanambi, located in the Irrigated Perimeter of Ceraíma, Rural Zone of the municipality of Guanambi, southwestern region of Bahia, with a latitude of 14° 13` S, longitude of 42° 46` W, and altitude of 545 m. According to the Köppen classification, the local climate is type Aw (hot and dry semiarid), with an average temperature of approximately 25.6 °C and an average annual precipitation of 680 mm with a rainy period between November and March.

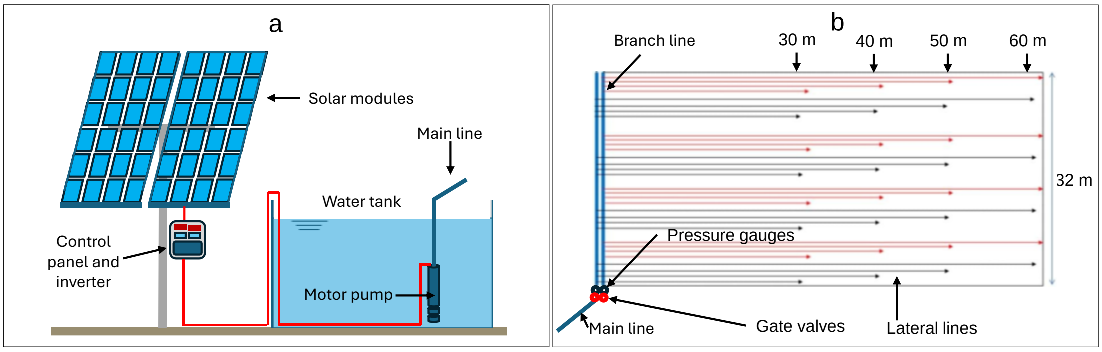
The work was developed in two stages. In stage 1, the system was hydraulically sized to identify the maximum and minimum lengths at their respective service pressures to provide smaller pressure variations on the lateral line. In stage 2, the equipment was assembled in the field, and water application uniformity tests were carried out via Christiansen uniformity coefficients (CUC) (Christiansen, 1942), distribution uniformity (CUD) (Criddle *et al.*, 1956) and statistical uniformity (CUE).

The motor pump system was installed in a fiber water tank with a capacity of 2,000 liters installed on the surface of the ground, which was supplied with water piped from the dam, since the region of Ceraíma (location of the *campus* where the experiment was conducted), which is an irrigated perimeter.

Therefore, to conduct the analyses, the water that supplied the reservoir was released, and the solar photovoltaic system was turned on immediately afterwards. This prospectus (Figure 1) was intended to simulate the use of the aforementioned system in irrigation with surface water, such as canals, lakes and dams.

A 1 hp submersible motor pump was used, with an electric current of 2.1 A, three phases, a voltage of 220/380 V, a head of up to 100 mca and flow rates between 500 and 3,000 $L\ h^{-1}$. The system (Figure 1) had 4 polycrystalline solar modules, with each plate capable of offering 335 W of power, a control panel and an inverter of 800 $W\ m^{-2}$, which provided a maximum electrical current of 8.7 A and a maximum voltage of 34.8 V (characteristics of the boards for an environmental condition of 20 °C and a wind speed of 1 ms^{-1}), where there was a low level of dirt on site. The dripper tube had internal and external diameters of 13.8 and 16 mm, respectively, and the emitters were installed internally at a spacing of 25 cm, a flow rate of 2.2 $L\ h^{-1}$, and a service pressure of 101 kPa. In this way, the system works at a pressure of 101 KPa, with 6 lateral lines of 60 m in operation.

Figure 1. Schematic of the energy generation and water capture system (a) and the irrigation system with different lengths of lateral lines (b) used in the test



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Another characteristic that we sought to simulate through the distance between the reservoir and the experimental area was the loss of pressure in the main line piping, which had a total length of 144 m from the reservoir outlet to the beginning of the area and a negligible difference in level; for sizing purposes, a pressure loss of approximately 80 KPa along the main line was considered.

The main line was made of rigid PVC, DN 50, PN 40, with a length of 114 m, a commonly used material that met the project specifications. The combined branch lines corresponded to 60 m (one measuring 32 m and the other measuring 28 m), with the same diameter and service pressure as the main line. Four lengths of lateral lines were installed: 30, 40, 50 and 60 m, with eight repetitions for each length, totaling 1,440 meters. At the beginning of the bypass line, three glycerin manometers and a piezometer were installed to check the pressure at the beginning of the area, and a 2” disc filter was used. To determine the flow rate, 128 plastic containers were used, which were placed at previously measured collection points to collect water, and a 250 mL beaker was used for measurement.

The pressures and lengths of the lateral lines (30, 40, 50 and 60 m) were previously dimensioned via hydraulic calculations via the Darcy–Weisbach equation and the Colebrook–White equation for the friction factor, and the maximum values of 10% and minimum values of 4% for flow variation (ΔQ) were considered.

To estimate the lengths of the lateral lines and dimensions of the aforementioned irrigation system, Equations 1, 2, 3, 4 and 5 were used:

$$\mathrm{Pin} = \mathrm{PS} + (0.75 \ \mathrm{x}\ \mathrm{hfL}) \pm 0.5 \ \mathrm{x}\ \Delta\mathrm{NL} \qquad (1)$$

On what,
Pin is the pressure at the beginning of the lateral line, in m;
PS is the sender's service pressure, in m;
hfL is the pressure loss on the lateral line, in m; it is expressed as
ΔNL is the variation in unevenness in the line, in m.

$$\mathrm{hf} = \mathrm{f}\ \mathrm{x} \left(\frac{\mathrm{L}}{\mathrm{D}}\right) \mathrm{x} \left(\frac{\mathrm{V}^2}{2\mathrm{g}}\right) \mathrm{x}\ \mathrm{F} \qquad (2)$$

On what,
hf is the localized pressure loss, in m;
f is the dimensionless friction factor;
L is the length of the pipe, in m;
D is the diameter of the pipe, in m;
V is the speed of the water, in ms $^{-1}$;
g is the acceleration due to gravity, in ms^{-2}; it is
F is the pressure loss correction factor for multiple outlet conduits and is dimensionless.

$$\mathrm{g} = 9.8616 - (2.5928 \ \mathrm{x}\ \cos(2\varphi)) + (0.0069 \ \mathrm{x}\ (\cos(2\varphi))^2 - (0.3086 \ \mathrm{x}\ \mathrm{H}) \qquad (3)$$

On what,
φ is the latitude, in degrees; it is
H is the altitude, in km.

$$\mathrm{f} = \left(\frac{1}{-2\log\left[\left(\frac{\varepsilon\mathrm{abs}}{3.71\mathrm{D}}\right) + \left(\frac{2.51}{\mathrm{NR}\sqrt{\mathrm{f}}}\right)\right]}\right)^2 \qquad (4)$$

On what,
f is the calculated, dimensionless friction factor;
εabs is the absolute roughness, and 0.001 mm^{-1} was used for polyethylene (Azevedo Neto *et al.*, 1998);
NR is the dimensionless Reynolds number.

$$\mathrm{NR} = \frac{(\mathrm{V}\ \mathrm{x}\ \mathrm{D})}{\rho} \qquad (5)$$

On what,
where ρ is the kinematic viscosity, in m s$^{-2,}$ for a water temperature of 20 °C.

Karmelli (1975) was used to determine the distribution of water in an irrigation system, which consists of checking the flow of the following emitters: first emitter, 1/3 of the length, 2/3 of the length and the last transmitter of the lateral line (LL). This procedure was carried out on the first derivation line (LD) in the sector; in the LL located at a distance of 1/3 of the total length of the LD; in the LL located at 2/3 of the total length of the LD; and in the last LL, which is located at the end of the LD.

Three flow determinations were carried out throughout the day, which were carried out in the morning, at noon and in the afternoon, at different times in each series of observations. In this way, we sought to evaluate the functioning of the system at the following times: between

7:00 and 9:30 am, in the morning; between 11:30 and 13:00, during the midday period; and between 4:00 pm and 5:30 pm, in the afternoon. With this, it was possible to determine an efficiency curve for the system and, therefore, endorse the use of irrigation management.

To carry out the assessments, initially, the irrigation system was turned on for a minimum period of 10 minutes until all the lines were dripping, and the pressure at the beginning of the area was checked. After this verification was verified, the irrigation system was turned off, and all 128 plastic collectors were placed. Once this process was complete, the system was turned on again for exactly 3 minutes and then turned off definitively to measure the volume of water collected.

With the aid of a beaker with a capacity of 250 mL, the volume of each collector was checked and immediately recorded in a spreadsheet containing the data obtained. A total of 768 collections were carried out in the 3 observation periods, which generated sufficient information to evaluate the efficiency of the photovoltaic energy generation system, the object of this work.

After sizing and assembling the equipment in the field, we moved on to stage 2, collecting water from the emitters to measure the flow along the lateral lines of the system to verify its uniformity of water application in drip irrigation with the use of photovoltaic solar modules for energy generation.

Thus, on the basis of the uniformity values that were found, proposed adjustments could be made, if necessary, so that the system achieves the desired water application uniformity.

Therefore, these checks were carried out in two situations: the first, with the opening of all lateral lines, without calibrating the service pressure at the beginning of the experimental area, so that it was possible to observe how the system behaves through prior sizing; and the second, with the closing of the side line exiting and adjusting the pressure at the beginning of the area to 101 KPa. The pressure values were visualized with the aid of 2 glycerin manometers installed, one at the pump outlet and the other at the beginning of the experimental area.

The assessment of water distribution uniformity was carried out according to the methodology proposed by Keller and Karmelli (1975), using the coefficients of Christiansen uniformity (CUC) (Christiansen, 1942), uniformity of distribution (CUD) (Criddle *et al*., 1956) and statistical uniformity (CUE) (Wilcox; Swailes, 1947), equations 6, 7 and 8, respectively.

$$\mathrm{CUC} = 100\left(1 - \frac{\sum_{i}^{n} |\mathrm{Qi} - \mathrm{Q}|}{\mathrm{nQ}}\right) \qquad (6)$$

On what,
Christiansen uniformity coefficient (%);
Qi is the flow rate of each emitter (L h^{-1});
Q is the average of the flows collected from each dripper (L h^{-1}); it is calculated as follows:
n is the number of collections.

$$\mathrm{CUD} = \left(\frac{\mathrm{q25\%}}{\mathrm{qm}}\right) \mathrm{x}\ 100 \qquad (7)$$

On what,
CUD is the distribution uniformity coefficient (%);
q25% is the average of the lowest quartile among the collected flows (L h^{-1}); it is calculated as
qm is the average flow rate between all the emitters (L h^{-1}).

$$\mathrm{CUE} = 100\ \mathrm{x}\left(1 - \frac{\mathrm{Sd}}{\mathrm{Qmed}}\right) \qquad (8)$$

On what,

CUE is the statistical uniformity coefficient (%);

sd is the standard deviation of the flow values collected (L h^{-1}); it is expressed as

Qmed is the average of the flows collected from all the emitters (L h^{-1}).

To interpret the values of CUC, CUD and CUE, Table 1 was used according to Mantovani (2001), which assigns, on the basis of the results obtained, classification to the irrigation system according to the calculations of water application uniformity indices.

Table 1. Classification of CUC, CUD and CUE values

CLASSIFICATION	CUC (%)	CUD (%)	CUE (%)
Great	> 90	> 84	90 - 100
Good	80 - 90	68 - 84	80 - 90
Reasonable	70 - 80	52 - 68	70 - 80
Bad	60 - 70	36 - 52	60 - 70
Unacceptable	< 60	< 32	< 60

Source: Mantovani (2001).

The method used for field research was quantitative, using the observation of pressure at the beginning of the area, according to its respective verification time and recording of the power provided by the system, whose flow measurements were measured in eight repetitions. for each lateral line length (30, 40, 50 and 60 m), with four checks along each lateral line, that is, 32 checks for each line length, totaling 128 collection points throughout the experimental area.

A piezometer was used to check the pressure that the water reached at the beginning of the bypass line, since when all the lateral lines were opened, the pump did not offer the necessary power to obtain satisfactory uniformity values; that is, it was not possible to check such pressures on the glycerin pressure gauges installed at the beginning of the area.

In a comparative analysis, the uniformity of water application was also verified when the system was calibrated so that the service pressure at the beginning of the area was maintained at 101 kPa.

3 RESULTS AND DISCUSSION

3.1 Ideal Length Analysis

The maximum and minimum lateral line lengths were calculated to serve as initial parameters so that the ideal line length interval would be known, following literature recommendations, to prevent any differences in water application from occurring. Therefore, the calculated line length values are described in Tables 2 and 3 below.

Table 2. Maximum lateral line lengths, according to pressure loss (hf), working pressure (PS) and pressure at the beginning (Pin) of the lateral line, for polyethylene pipes with a diameter equal to 13 mm.

L (m)	hf (KPa)	PS (KP)	Pin (KPa)
56	7.922	40.0	45.941
56	8.778	45.0	51.584
57	12.669	65.0	74.502
58	17.509	89.0	102.132
58	20.865	108.9	124.549
59	25.716	131.1	150.387

Source: prepared by the authors

Table 3. Minimum lateral line lengths, according to pressure loss (hf), working pressure (PS) and pressure at the beginning (Pin) of the lateral line, for polyethylene pipes with a diameter equal to 13 mm

L (m)	hf (KPa)	PS (KPa)	Pin (KPa)
40	3.661	47.1	49.870
41	5.555	70.6	74.852
42	7.420	89.0	94.431
42	7.611	94.2	99.957
42	9.239	117.8	124.740
43	11.547	141.3	150.030

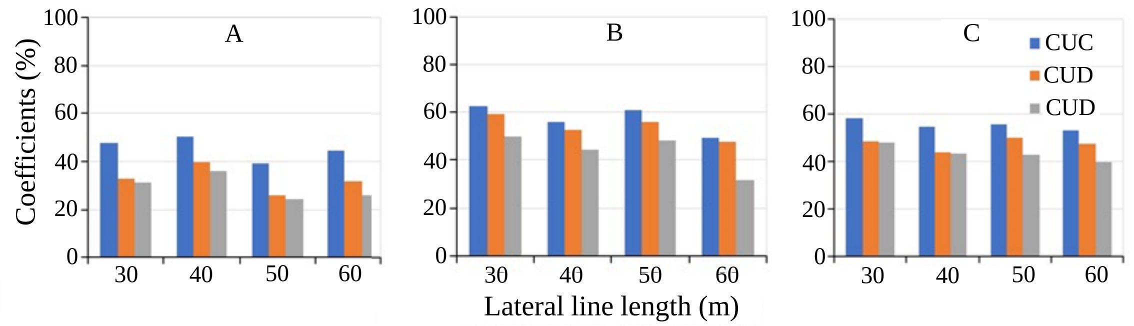
Source: prepared by the authors

As shown in Tables 2 and 3, as well as the established criteria, the maximum and minimum lengths for the lateral line corresponded to 59 and 40 m, respectively. However, for the purpose of the experiment, four lengths were adopted for the lateral line, namely, 30, 40, 50 and 60 m, with the aim of verifying, under field conditions, what was dimensioned for the aforementioned system.

3.2 Uniformity test with all sides open

The field analysis served to validate the previously made dimensioning, and after all the data throughout the research analysis period were tabulated, calculations were made for the Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and coefficient of statistical uniformity (CUE). Figure 2 shows the coefficients described for each length of the lateral line, with opening of all lines and without calibration of the service pressure, for the morning, midday and afternoon periods.

Figure 2. Water distribution uniformity coefficients in the morning (A), midday (B) and afternoon (C) without calibration of the service pressure



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The results expressed in Figure 2 demonstrate, upon comparison with the parameters prescribed by Mantovani (2001), the inefficiency of the method used.

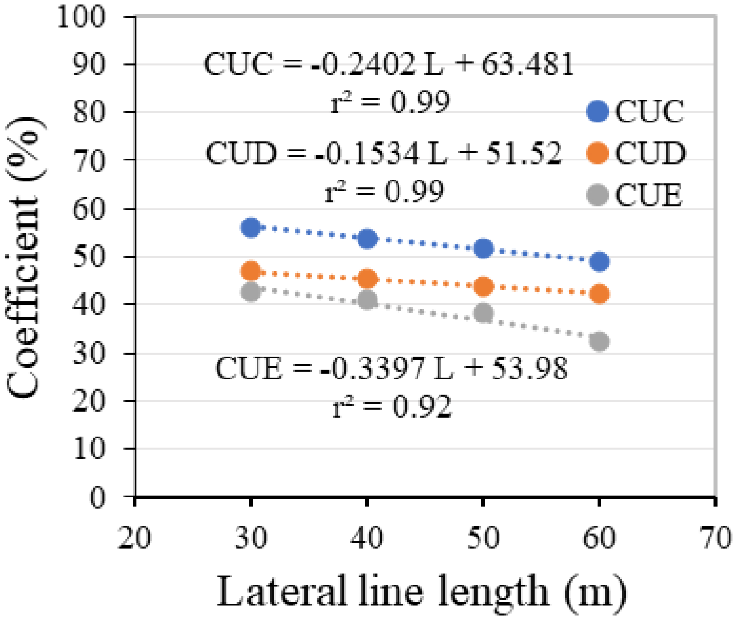
However, observing the results separately, it appears that the highest values for the coefficients were concentrated in the midday analysis period, in which the CUC, CUD and CUE values corresponded to levels above 60%, 55% and 45%, respectively, for line lengths of 30 and 50 m.

The data from the method used also allow us to infer that, for the midday period, the system can be classified as bad from the CUC point of view, reasonable from the CUD index and unacceptable from the CUE analysis. This behavior demonstrated by the system can be explained by the noncalibration of the service pressure, since the total opening of the lateral lines caused a service pressure far below (approximately 17 KPa) what the equipment needs to provide the flow (2.0 L h^{-1}) proposed by the manufacturer.

Furthermore, the morning period was the observation window with the lowest efficiency indices, whose CUC, CUD and CUE values varied from 40--50%, 32--39% and 31--36%, respectively, for lengths of 30 and 40 m, highlighting the length of 40 m as the most efficient for the calculated coefficients.

In the morning, the method used was categorized as unacceptable for two of the coefficients (CUC and CUE) and bad from the CUD point of view. Figure 3 shows the estimates of the CUD, CUD and CUE, regardless of the evaluation time, depending on the lengths of the lateral lines. Notably, for any coefficient analyzed, the uniformity of the water distribution decreases with increasing length of the LL.

Figure 3. Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and statistical uniformity coefficient (CUE) independent of the evaluation time and without service pressure calibration for different lengths of lateral lines



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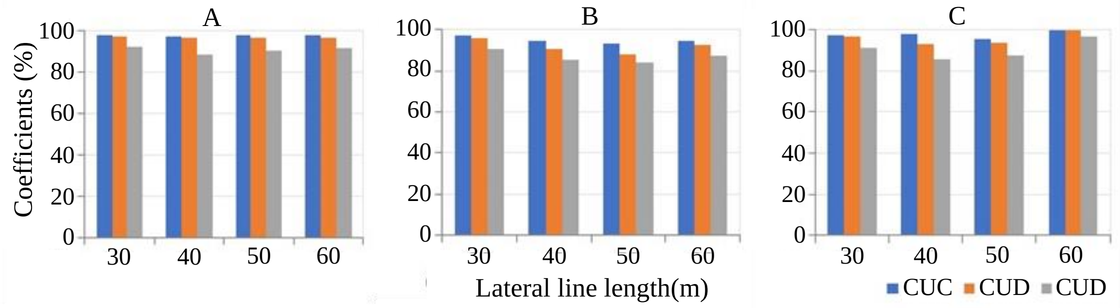
When analyzed together, without calibration of the service pressure and regardless of the observation time, the data obtained allow us to state that the system presented CUC, CUD and CUE values above 55%, 45% and 40%, respectively, for lengths of 30 and 40 meters.

The data in Figure 3 also indicate that, without calibrating the service pressure at the beginning of the derivation line, the water distribution uniformity of the system is very low, which makes the proposed method in the aforementioned photovoltaic system not recommended for use.

3.3 Uniformity test with pressure calibration at the beginning of the bypass line

Figure 4 shows the coefficients described for each lateral line length, with calibration of the service pressure at 101 KPa for the morning, midday and afternoon periods.

Figure 4. Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and statistical uniformity coefficient (CUE) in the morning (A), midday (B) and afternoon (C) with calibration of the working pressure at 101 kPa



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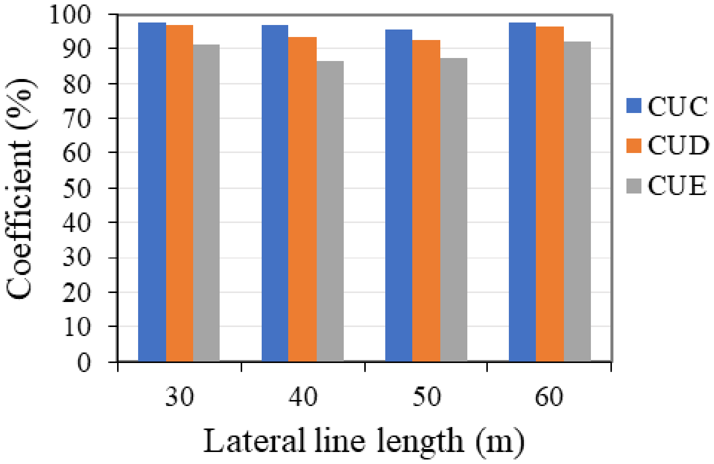
The data that make up Figure 4 below indicate the averages for the values of CUD, CUD and CUE, regardless of the evaluation time, in the four lateral line lengths, with calibration of the service pressure at 101 KPa through the closure of the line length.

Figure 5. Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and statistical uniformity coefficient (CUE) with service pressure calibration at 101 kPa, regardless of the time of day



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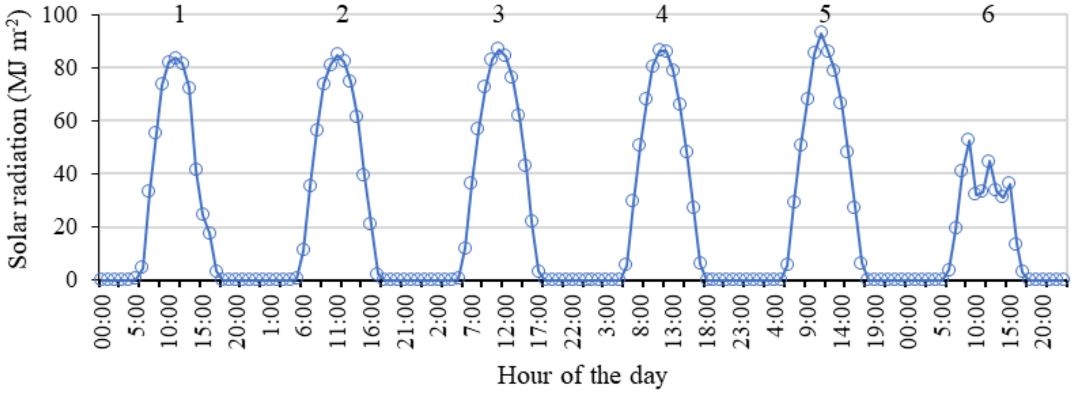
An analysis of Figures 4 and 5 reveals that, regardless of the observation time, the data obtained indicate that the method presented values above 90% for the CUC and CUD coefficients and a CUE above 85% for all the lateral line lengths used. Therefore, for all the line lengths tested (30, 40, 50 and 60 m), when the service pressure at the beginning of the area at 101 kPa is calibrated, by closing any length of line used, the system behaves excellently from the point of view of the uniformity of water application and according to the parameters prescribed by Mantovani (2001).

By evaluating the average statistical uniformity coefficient (CUE) of a drip irrigation system, Lima *et al*. (2017) reported values of up to 93.15%, as did the application efficiency (Ea), which was analyzed at five different service pressures. In the present work, values above 80% and up to 91% were verified, which classifies the system as very satisfactory from the point of view of the uniformity of the water distribution to the plants.

For all the lengths of the lateral lines tested (30, 40, 50 and 60 m), the results were satisfactory after the pressure regulation method was applied at the beginning of the area and unacceptable without this procedure.

Another detail that was further demonstrated in Figures 4 and 5 was the direct influence of the environment on the uniformity of water application. Notably, lengths of 30 to 50 m resulted in relatively lower uniformity than 60 m, which can be explained by the influence of radiation (Figure 6). The data collected at lengths of 40 and 50 m were influenced by the oscillation of solar radiation on the last day, at the time of measurement, which caused greater variation in flow values and, consequently, lower uniformity coefficients; for example, the value of the CUD for the 50 m long lines (Figure 4B) was 88%, whereas for the 60 m long lateral lines (Figure 4C), it was 99.6%. On the other hand, for the length of 30 m, owing to the shorter length, which consequently caused less load, it resulted in less flow variation and thus higher uniformity coefficients.

Figure 6. Solar radiation on water collection days for the two methodologies used were 1 (09/24/2020), 2 (09/25/2020), 3 (09/27/2020), 4 (23rd/03/2021), 5 (03/24/2021) and 6 (04/08/2021). Guanambi, BA



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Furthermore, regarding the recording of solar radiation carried out by the meteorological station installed on the Guanambi *campus* of IF Baiano, the minimum values of radiation capable of generating energy were observed at 6:06 am in the morning and at 5:00 pm:48 h in the afternoon, with average values of 2.65 and 4.01 MJ m^{-2}, respectively.

Moreover, the electrical voltage in Volts and the power produced in Watts reached average values of 69.2 and 1,348, respectively, within the data observation period. Notably, data collection took place with the system operating under full sunlight conditions; that is, no clouds capable of influencing the results were observed. This rules out the hypothesis that the system's inefficiency could be caused by a lack of solar radiation, which would result in low energy production.

4 CONCLUSIONS

Given the results observed in the two methods used, the photovoltaic energy generation system used in the research, with a pump power of 1 hp and 4 photovoltaic solar modules, proved to be efficient in terms of uniformity of water application, with values of coefficients of acceptable uniformities, regardless of the period of the day observed and with lateral line lengths of 30 to 60 m, operating with control of the service pressure at the beginning of the area. On the other hand, the system behaves inefficiently when there is no calibration of the service pressure at the beginning of the area; therefore, the photovoltaic system must be sized to meet the pressure and flow requirements of the irrigation system.

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