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PHOTOVOLTAIC PUMPING: ALTERNATIVE FOR MICROIRRIGATION IN THE MATA MINEIRA AREA

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1 ABSTRACT

The objective of the research was to evaluate the uniformity of drip irrigation with photovoltaic pumping with and without storage in batteries, using normal and self-compensating emitters. The experiment was conducted at the Federal University of Viçosa, Minas Gerais, Brazil. Two drip irrigation systems were tested, one with self-compensating emitters and the other with normal emitters with a flow rate of 4 L h-1. The coefficients of uniformity of Cristiansen and distribution (CUC and CUD) were used to evaluate the performance of the irrigation systems. The volumes pumped by the autonomous system and stored in batteries throughout the year in all regions of the country were compared for the period from 02/01/2018 to 01/31/2019, a period that contemplates the data collection phase of the experiment. According to the results the uniformity of the drip systems with and without energy storage with emitters normal and self-compensating presented a coefficient between 93% and 97%, classified as excellent. The largest volumes pumped throughout the year for drip irrigation systems with normal and self-compensating emitters without batteries occurred in the Northeast region of Brazil.

Keywords: drip irrigation, hydraulic performance. efficiency of application. solar radiation

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2 RESUMO

O objetivo da pesquisa foi avaliar a uniformidade da irrigação por gotejamento com bombeamento fotovoltaico com e sem armazenamento em baterias, utilizando emissores normais e autocompensantes. O experimento foi conduzido na Universidade Federal de Viçosa, Minas Gerais, Brasil. Dois sistemas de irrigação por gotejamento foram testados, um com emissores autocompensantes e outro com emissores normais com vazão de 4 L h-1. Para avaliar o desempenho dos sistemas de irrigação, foram utilizados os coeficientes de uniformidade de Cristiansen e de distribuição (CUC e CUD). Os volumes bombeados pelo sistema autônomo e armazenados em baterias ao longo do ano em todas as regiões do país foram comparados para o período de 01/02/2018 a 31/01/2019, período que contempla a fase de coleta de dados do

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experimento. De acordo com os resultados, a uniformidade dos sistemas de gotejamento com e sem armazenamento de energia, com emissores normais e autocompensantes apresentou coeficiente entre 93% e 97% classificado como excelente. Os maiores volumes bombeados ao longo do ano para sistemas de irrigação por gotejamento com emissores normais e autocompensantes sem baterias ocorreram na região Nordeste do Brasil.

Keywords: Gotejamento. Desempenho hidráulica. Eficiência de aplicação. Radiação solar

3 INTRODUCTION

The conversion of solar radiation in the energy by using photovoltaic systems has been the ideal and sustainable potential option for the pumping of water. Demand for renewable energy, such as photovoltaic energy, has an impact on the reduction of energy availability that negatively impacts the environment (CHAND; and KALAMKAR, 2016).

In Brazil, photovoltaic energy is of great importance, mainly in the Northeast region. This region is gifted presented through with several hours of sunshine. In February 2019, the country had the power of 1,987.719 kW, representing 1.21% of the energy generated (ANEEL, 2019),

The use of photovoltaic systems presents a high initial investment for the installation, which is attenuated with the reduced by the reduction in the maintenance cost of throughout the photovoltaic system life cycle (ALLARDYCE et al., 2017). Burney et al. (2010) point out that the initial design of photovoltaic systems for irrigation, are it still presents competitive concerning oscillations of due to high prices of fossil fuels.

An irrigated farmer can consume water and electricity consumption to meet the water demand of crops. Traditionally, pumping is done using disconnected networks when possible, or diesel generators in remote regions (LORENZO et al., 2019). Sontake and Kalamkar (2016) highlight the photovoltaic systems for water pumping for irrigation in a natural relationship between the water requirement and the availability of solar energy. The performance of the photovoltaic system is directly influenced by the solar irradiation, temperature, and efficiency of the monocrystalline cells.

The drip irrigation system plays an important role in regions with water availability, being one of the main irrigation tools in agricultural areas. This system can be an excellent tool for the management of water resources, favoring increases in the productivity of water use, and the development and sustainability of the agricultural sector (BUSH et al., 2016). The increase in the flow demand for the operation of the irrigation systems should highlight the possibility of using photovoltaic energy to activate the system (KELLEY et al., 2010).

The present work evaluated aimed to evaluate the hydraulic performance of the drip irrigation system coupled to the photovoltaic pumping with and without batteries.

4 MATERIAL E MÉTODOS

The irrigation system was set up in the Irrigation Experimental Area of the Department of Agricultural Engineering (DEA) at the Federal University of Viçosa (UFV), Viçosa - MG. Brazil.

Two sets of submerged solar-powered solar photovoltaic pump model Anauger® Solar R100 were used. The set consists of a 175 Wp monocrystalline solar module with 36 Vdc voltage with a driver (ANAUGER, 2019). A set of pumps was designated as a photovoltaic system without energy storage (WB) and installed following the manufacturer's recommendations. The other battery-powered system (B) has been adapted for three Heliar Freedom DF1000 70 Ah 12V batteries connected in series, and a Viewstar VS3048AU 30 A 36 V charge controller.

Two pumps were installed in a 1000 L PVC water box on the side of the photovoltaic panels. The water was then moved to the irrigation system by a PVC pipe with a nominal diameter of 32mm.

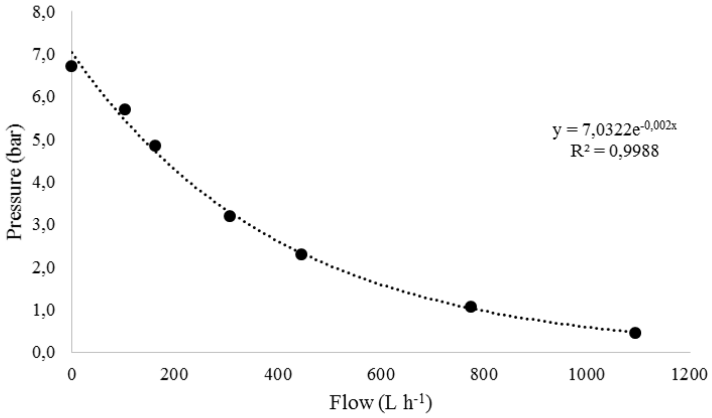
The experiment was carried out in the Southern Hemisphere, the photovoltaic panels were positioned to the geographical north, with a slope similar to the local latitude (ALVARENGA; FERREIRA; FORTES, 2014).

As a measure of solar radiation (W m^{-2}) was loaded by the Davis Vantage Pro 2® automatic weather station installed at 1.5 m of the non-local height of the experiment. Data were collected at five minutes intervals.

The pressure readings were performed with the aid of the Bronze Digital Manometer - VKP - 064 positioned before the hydrometer. The minimum and maximum pressures for each test were recorded. The release was done through the analog hydrometer interface and time. The beginning and end of the whole test were made as volume readings without apparatus the average flow rate being measured.

For the conditions of the experiment, a curve of the pump with the flow was obtained, using the pump at maximum power and in constant operation (Figure 1).

Figure 1. Anauger pump characterization for the research condition.



For each pumping system two drip systems were tested, one with a normal iDrop drip button (Irritec) at 1 bar pressure and the other self-compensating iDrop drip button (Irritec) with a pressure of 0.5 to 4.5 bar both of flow 4 L h^{-1}. The irrigation systems were composed of seven lateral lines spaced 0.8 in 0.8 m with each lateral line containing 22 emitters spaced 0.5 in 0.5 m totaling 154 emitters per system. The irrigation system was designed to meet the pumping capacity of the pump.

In general, the application uniformity evaluations were performed for four systems characterized as follows: irrigation system with normal emitter with pump without storage of energy in batteries (NWB) irrigation system with self-compensating emitter with pump without storage (SCWB), irrigation system with normal emitter with pump with energy storage in batteries (NB) and irrigation system with self-compensating emitter with pump with energy storage in batteries (SB).

The evaluations were carried out between October 24 and November 30, 2018. The tests for the NWB and SCWB were performed on random days and times, with cloud conditions fluctuating between clear, partly cloudy, and cloudy days, to represent conditions with varied availability of solar radiation. We performed 24 uniformity tests for each system.

For the evaluation of the autonomy of the charged batteries, three tests were performed using the same simulated irrigation system, between December 01 and 05, 2018. From the total recharge of the batteries, the system was turned on and operated until it was turned off by the controller, charge. With the three tests, the average volume pumped with the fully recharged batteries was obtained.

Considering the evaluation period, the hourly brightness index was determined to classify the sky as cloudiness and ensure the variation of solar radiation at the time of NWB and SCWB (Equation 1) tests, according to Duffie and Beckman (1980).

$$K_t^h = \frac{Rs}{Ra} \qquad (1)$$

Where: K_t^h- lightness index. dimensionless; Rs – hourly solar radiation, W m^{-2}; Ra – hourly radiation at the top atmosphere, W m^{-2}.

The average hourly solar radiation measured by the automatic meteorological station was used for each test and Ra was calculated according to Allen *et al.* (1998). According to Escobedo *et al.* (2009) the time clarity index can be classified into four intervals, being: $K_t^h \leq 0.35$ cloudy sky, $0.35 < K_t^h \leq 0.55$ partly cloudy with a predominance of the diffuse component of solar radiation, $0.55 < K_t^h \leq 0.65$ partly cloudy with a predominance of the direct component of solar radiation and $K_t^h > 0.65$ clear sky.

The evaluation of system uniformity was performed according to the methodology of Keller and Karmeli (1975) with the modification proposed by Denículi *et al.* (1980). This methodology consists of the data collection in four lateral lines (first line, 1/3 line and 2/3 of the origin and last line), with a study of eight emitters per line (first emitter, emitters 1/7, 2 / 7, 3/7, 4/7, 5/7 and 6/7 of origin, and last issuer), totaling 32 collection points.

The coefficient of uniformity of Christiansen (Equation 2), proposed by Christiansen (1942), and the distribution uniformity coefficient (Equation 3) proposed by Criddle *et al.* (1956) were determined.

$$CUC = \left(1 - \frac{\sum |Li - Lm|}{n.Lm}\right).100 \qquad (2)$$

Where: CUC – Christiansen uniformity coefficient, %; Li – depth collected at the emitter “i”, mm; Lm - average depth of all observation, mm; and n – number of collected emitters.

$$CUD = \left(\frac{L_{25}}{Lm}\right).100 \qquad (3)$$

Where: CUD – distribution uniformity coefficient, %; L25 - average of the lower quartile of the emitter’s depth, mm; and Lm – average depth of all observation.

The pumping potential with the photovoltaic plate for different regions of Brazil was evaluated from equations to estimate the mean flow pumped to the battery-free drip systems (NWB and SCWB) from solar radiation. These equations were applied to the Rs data from the National Meteorological Institute (INMET) network of automatic meteorological stations (EMA). The period evaluated was one year, from January 2018 to January 2019.

The INMET EMA network has 581 stations throughout Brazil that provide hourly values of Rs. INMET provides data of Rs in MJ m^{-2} h^{-1} and conversion to W m^{-2} is required. The estimation of the pumped volume per hour considered the hourly Rs made available by the stations. The hourly volumes considered periods of 24 hours corresponding to their date, and then, it was computed the average daily volume pumped for the months evaluated.

The non-parametric Kruskal-Wallis test (CONOVER, 1980) was used to verify if there was statistical difference between the calculated values of CUC and CUD of the four systems. The multiple comparison test used was the smallest significant Fisher difference (LSD) (CONOVER AND IMAN, 1981), applied with the Bonferroni correction (SHINGALA; RAJYAGURU, 2015). The analyzes were performed in software R (R CORE TEAM, 2018). Using the Agricolae Package (MENDIBURU, 2019).

5 RESULTADOS E DISCUSSÃO

According to the information obtained to characterize the brightness through the clarity index that was obtained for the system with normal emitters without battery (Table 1), the tests were performed in 47.3% under cloudy conditions, 5.3% partly cloudy with predominance of the diffuse component of the radiation, 31.6% partially cloudy, with predominance of the direct component of the radiation and 15.8% clear sky.

Table 1. Day, schedule, solar radiation, and clarify index (K_T^h) for each uniformity test in drip irrigation system normal emitter without batteries (NWB) in photovoltaic pumping and the classification of clarify index.

NWB						
Test	**Day**	**H. Start**	**H.End**	**Solar Rad. (w/m²)**	K_T^h	**Classification**
1	oct/24	09:27:00	09:43:00	508.8	0.58	PCDR
2	oct/24	13:09:00	13:28:00	316.6	0.21	C
3	oct/24	14:06:00	14:22:00	445.5	0.31	C
4	oct/24	15:05:00	15:22:00	415.4	0.32	C
5	oct/24	16:09:00	16:37:00	106.7	0.10	C
6	oct/25	08:34:00	08:56:00	345.0	0.63	PCDR
7	oct/25	10:10:00	10:28:00	418.0	0.36	PCDIR
8	oct/25	14:11:00	14:27:00	372.3	0.26	C
9	oct/25	15:09:00	15:27:00	183.2	0.14	C
10	oct/26	09:25:00	09:44:00	172.6	0.19	C
11	oct/29	11:49:00	12:09:00	191.4	0.14	C
12	nov/26	10:00:00	10:15:00	795.5	0.57	PCDR
13	nov/26	13:24:00	13:39:00	530.5	0.32	C
14	nov/27	09:09:00	09:24:00	684.3	0.60	PCDR
15	nov/27	10:37:00	10:52:00	795.3	0.57	PCDR
16	nov/27	12:24:00	12:39:00	956.3	0.58	PCDR
17	nov/27	12:57:00	13:13:00	970.0	0.59	PCDR
18	nov/27	13:30:00	13:45:00	1230.8	0.75	CS
19	nov/27	14:16:00	14:31:00	430.7	0.28	C
20	nov/27	14:44:00	15:01:00	303.0	0.20	C
21	nov/27	15:29:00	15:52:00	211.5	0.16	C
22	nov/28	10:09:00	10:26:00	412.8	0.29	C
23	nov/28	10:44:00	10:59:00	1032.8	0.73	CS
24	nov/28	12:54:00	13:07:00	1164.3	0.70	CS

In what: PCDR is partially cloudy with a predominance of the direct component of the radiation; C is cloudy; PCDIR is partly cloudy with a predominance of the diffuse component of the radiation and CS is clear sky.

Photovoltaic panels have a better performance in the period from 9 a.m. to 3 p.m., since in this period there is a higher incidence of solar radiation (ALVARENGA *et al.,* 2014). Thus, the clarity index allows characterizing the solar radiation of a region and to estimate the operation of the solar plates in photovoltaic systems for the pumping of water in the localized irrigation (GALDINO *et al*., 2016).

For the system with self-compensating emitters without battery (Table 2), 43.7%, 37.5%, 0.0% and 18.8% of the tests were obtained in cloudy conditions, partially cloudy with a predominance of the diffuse component of the radiation, partly cloudy with a direct component of the radiation and clear sky, respectively. Thus, it was observed that variation of the solar radiation occurred for the systems tested during the evaluation period.

Table 2. Day, schedule, solar radiation, and clarify index (K_T^h) for each uniformity test in drip irrigation with self-compensating emitter without batteries (SCWB) in photovoltaic pumping and the classification of clarify index.

SCWB						
Test	**Day**	**H. Start**	**H.End**	**Solar Rad. (w/m²)**	K_T^h	**Classification**
1	nov/12	12:29:00	12:47:00	639.8	0.40	PCDIR
2	nov/12	13:31:00	13:47:00	367.0	0.23	C
3	nov/12	15:04:00	15:19:00	899.8	0.69	CS
4	nov/23	10:57:00	11:12:00	552.0	0.35	C
5	nov/23	11:40:00	11:55:00	491.5	0.32	C
6	nov/26	09:03:00	09:18:00	286.0	0.25	C
7	nov/26	10:31:00	10:46:00	751.0	0.54	PCDIR
8	nov/26	12:00:00	12:16:00	782.5	0.47	PCDIR
9	nov/26	12:51:00	13:04:00	1285.3	0.78	CS
10	nov/27	09:49:00	10:05:00	1101.5	0.97	CS
11	nov/28	13:19:00	13:31:00	1106.7	0.67	CS
12	nov/28	13:41:00	13:53:00	352.3	0.21	C
13	nov/28	14:03:00	14:15:00	735.0	0.48	PCDIR
14	nov/28	14:24:00	14:39:00	335.3	0.22	C
15	nov/28	14:46:00	15:01:00	732.0	0.48	PCDIR
16	nov/29	09:09:00	09:25:00	349.0	0.30	C
17	nov/29	09:37:00	09:55:00	338.5	0.29	C

In what: PCDR is partially cloudy with a predominance of the direct component of the radiation; C is cloudy; PCDIR is partly cloudy with a predominance of the diffuse component of the radiation and CS is clear sky.

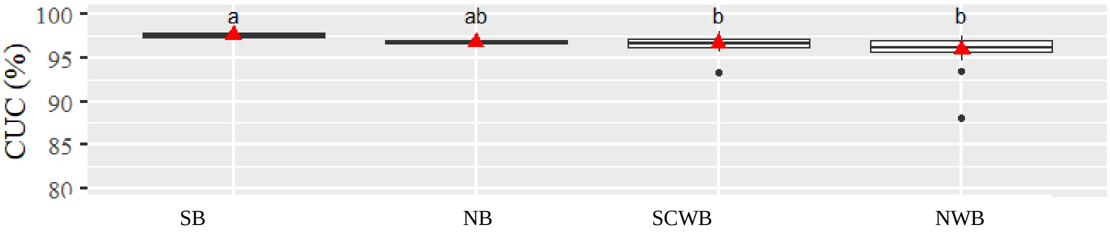
In Table 3, Figure 1 and Figure 2 it was observed that the tests that used the battery storage system presented statistically the highest values of CUC and CUD, in addition to exhibiting a lower degree of dispersion. This is due to the fact that the system operating at constant pressure and flow, since the load controller provides constant power to the pump. While in the without battery system there was oscillation of the pressure and flow during the tests due to the variation of the solar radiation incident on the photovoltaic panel.

Table 3. Average test about Christiansen Uniformity Coefficient (CUC) and Distribution Uniformity Coefficient (DUC) considering a photovoltaic system with batteries and without batteries in normal and self-compensating drip emitters.

System	CUC	Group	DUC	Group
SCWB	97.56	a	96.23	a
NWB	96.83	ab	95.19	ab
SCWTB	96.68	b	94.64	b
NWTB	95.88	b	93.31	b

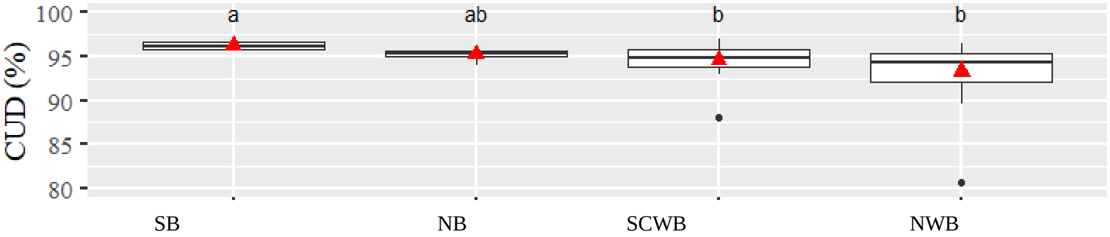
a = group of the higher average and b = group of smaller average.
When: SCWB is self-compensating dripper with batteries; NWB is normal dripper with batteries; SCWTB is self-compensating dripper without batteries and NWTB is normal dripper without batteries.

Figure 1. Multiple LSD comparison test for the observed CUC values for each irrigation system with normal emitter with pump without storage of energy in batteries (NWB). irrigation system with self-compensating emitter with pump without storage (SCWB), irrigation system with normal emitter with pump with energy storage in batteries (NB) and irrigation system with self-compensating emitter with pump with energy storage in batteries (SB).



. Averages (red symbol) followed by the same letter do not present statistical difference

Figure 2. Multiple LSD comparison tests for CUD values observed for each irrigation system with normal emitter with pump without storage of energy in batteries (NWB), irrigation system with self-compensating emitter with pump without storage (SCWB), irrigation system with normal emitter with pump with energy storage in batteries (NB) and irrigation system with self-compensating emitter with pump with energy storage in batteries (SB).



Averages (red symbol) followed by the same letter do not present statistical difference.

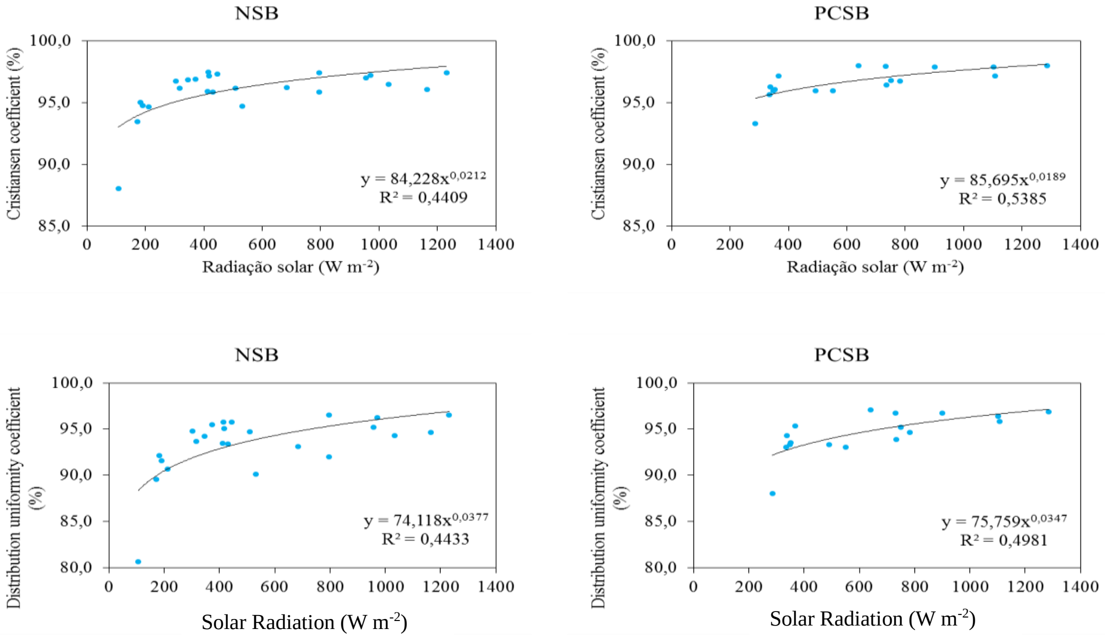
Considering the statistical results, it was possible to verify that the system with self-compensating emitters and batteries presented a better performance for the uniformity coefficients. This is because the system with batteries allows a smaller oscillation of the photovoltaic energy supplied for pumping ensuring the uniform distribution of the flows along the irrigation line.

After installing the irrigation pumping photovoltaic system it is essential to determine the efficiency of the application of the irrigation depth in accordance to the hydraulic characteristics of the system. The CUC and DUC are directly proportional coefficients and may indicate the uniformity of application of the irrigation depth along the lateral lines of the drip or micro-sprinkler system. Capra and Scicolone (1998) classify coefficients of uniformity higher than 90% as excellent. It is important to highlight that in drip irrigation systems the uniformity of application increases with the water supply and therefore it is fundamental that the photovoltaic system is efficient in pumping.

In addition to the uniformity of the localized irrigation system, the characterization of the emitters must be considered to ensure the characteristic flow rate of the system. This flow is defined by the characteristics of the emitters used in the irrigation line. Feng *et al.* (2018) have pointed out that the structural components of drip irrigation emitters may be an obstacle that restricts the proper application of the irrigation depth. Dalri *et al*. (2015) observed that the self-compensating emitters tend to be more efficient because they have a structure that facilitates the dissipation of pressure and the application of small, constant and uniform flows.

Figure 3 shows the regressions correlating solar radiation with CUC, CUD, and flow. It was possible to observe that the lower radiations reduce the uniformity of application and the flow, since the system is depending on the high solar radiation to reach the maximum capacity of pumping.

Figure 3. Cristiansen Uniformity Coefficient (CUC) and Distribution Uniformity Coefficient (DUC) considering solar radiation in irrigation system with normal (NWB) and self-compensating (SCWB) emitters and without batteries.

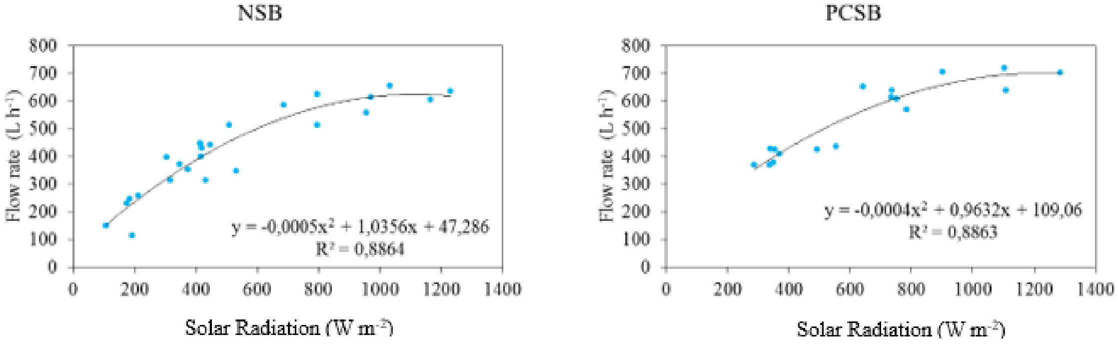


Analyzing the CUC and CUD as a function of the solar radiation, it was observed that as the solar radiation increases, an increase in the values of the uniformity coefficients occurs. The mathematical model that best describes this behavior is the potential. This adjustment represented that the successive increase of the solar radiation can favor the pumping and consequently the distribution of the water in the irrigation system, thus, guaranteeing greater uniformity.

In Figure 4, the flow, considering the systems with normal and self-compensating drip emitters, presented a second-degree polynomial fit for correlation with solar radiation. The coefficient of determination for the two systems shows that there was an association between flow and radiation, considering that they are close to 1. According to this model, there is a greater slope of the curve for smaller values of radiation, occurring later a saturation and decrease of the curve for higher values of solar radiation.

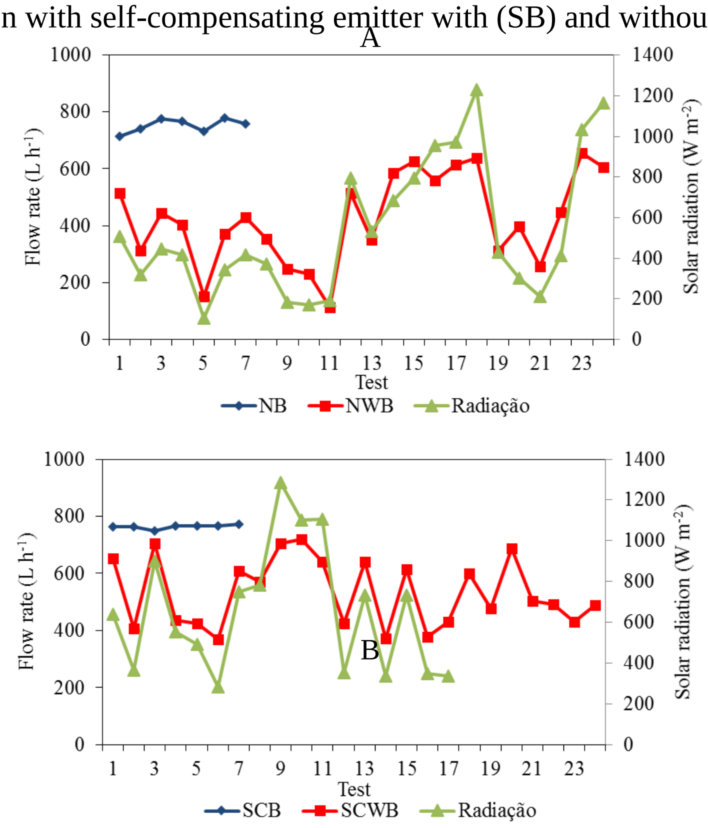
It was possible to identify that in the system with normal emitters the maximum flow, 583.5 L h^{-1}, was reached for solar radiation of 1035.6 W m^{-2}. This increase in the flow of 15.3% was due to the hydraulic characteristics of the self-compensating emitter, which allows pressure compensation and self-flow regulation. Also, solar irradiation was 16% higher and may have contributed to higher pumped flow.

Figure 4. Flow rate considering solar radiation in irrigation system with normal (NEWB) and self-compensating (SCEWB) emitters and without batteries.



In Figure 5, it was observed that the flow of the system with batteries presented a smaller variation, with a standard deviation of 24.63 L h^{-1} for the NB and 7.71 L h^{-1} for the SB. In the system without batteries, there was a variation between the higher flows accompanying the solar radiation variations. The standard deviation for NWB and SCWB were, respectively, 158.52 and 119.37 L h^{-1}. Therefore when there is no energy storage to keep the pumping drive constant, there is a variation of the volume of water pumped and, consequently, of the flow applied by the emitters.

Figure 5. Flow variation in irrigation system considering solar radiation in (A) drip irrigation with normal emitters with (NB) and without batteries (NWB) and (B) drip irrigation with self-compensating emitter with (SB) and without batteries (SCWB).



The pumping potential for Brazil (Figure 6 and 7) was calculated considering the observed Rs values and the flow equations correlating the solar radiation in Figure 4 during one year, considering the experimental period. The average monthly volume per station for the NWB and SCWB were presented in Figure 6 and Figure 7, respectively, being possible to observe the behavior of the volume pumped in the systems without storage in the energy in batteries. The number of meteorological stations were 506. The stations were used to determine the pumped volumes considering solar radiation.

Figure 6. Estimated average monthly volume pumped in Brazil in drip irrigation with normal (NEWB) emitters without batteries.

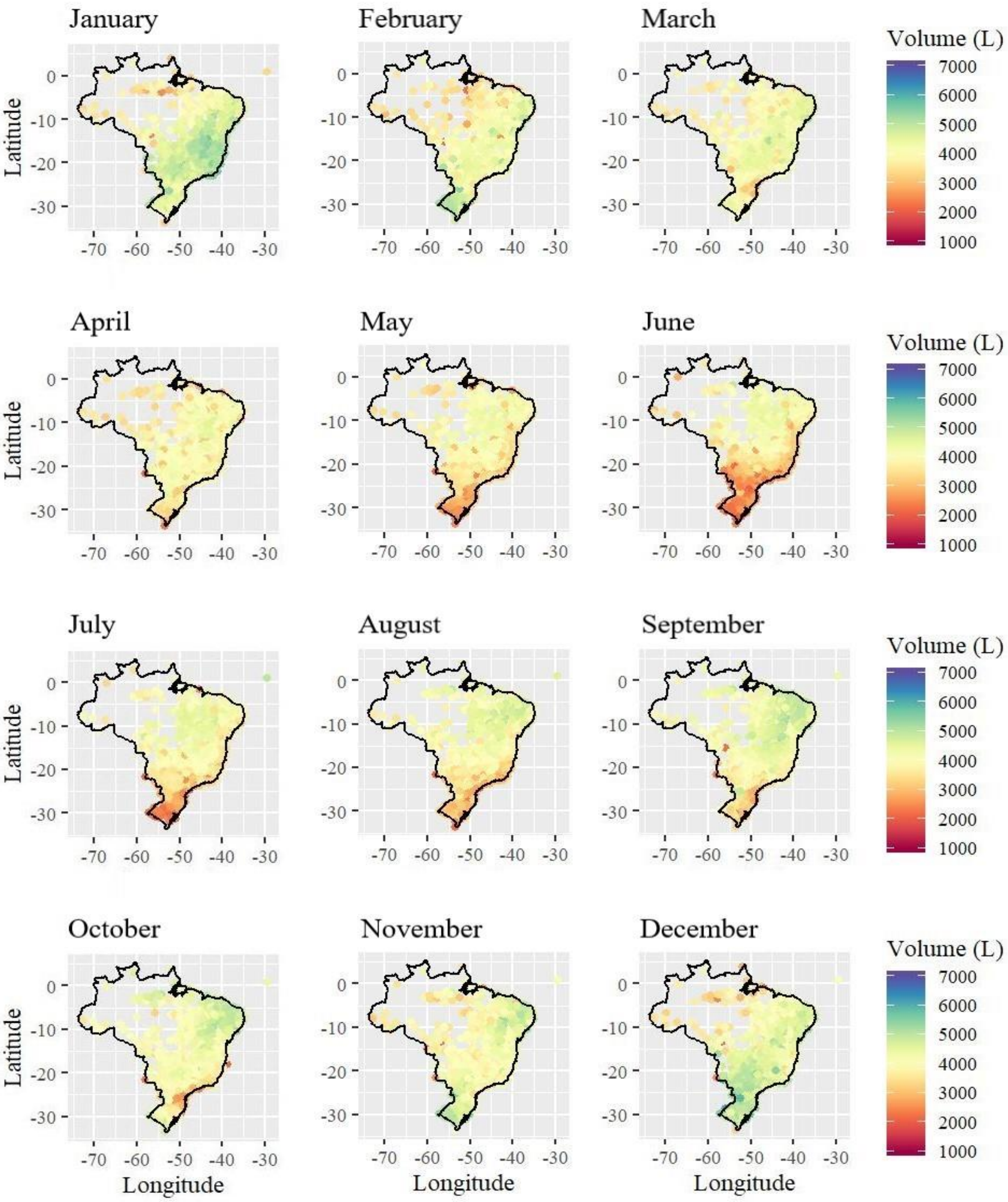
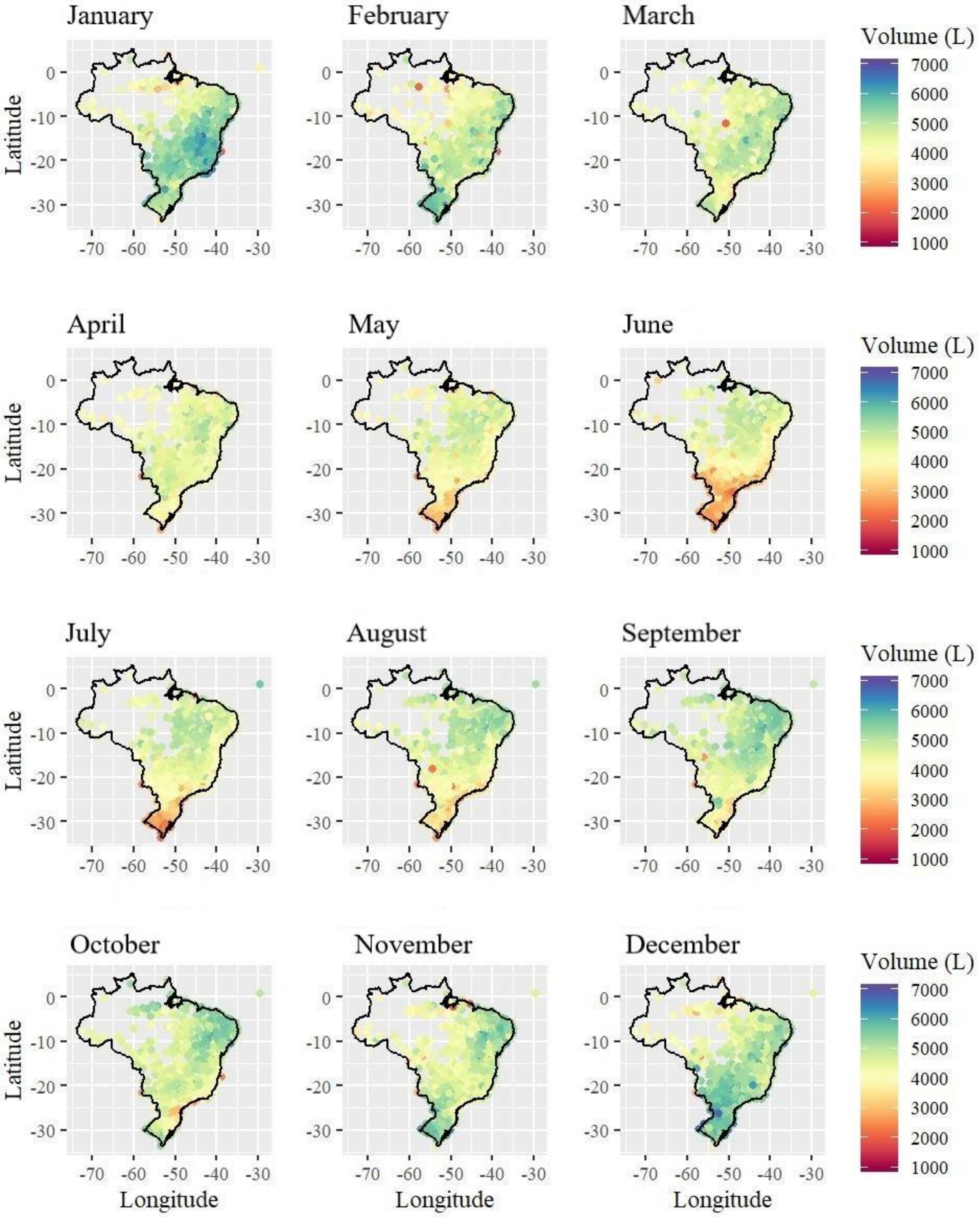


Figure 7. Estimated average monthly volume pumped in Brazil in drip irrigation with normal (SCEWB) emitters without batteries.



Across the country, it was noted that there was a variation of the monthly average volumes over the months for the two treatments. This behavior is due to the variation in the incidence of solar radiation throughout the year. The smallest variations occur in the Northeast because it is close to the Equator. In the South, the largest variations were observed due to the greater latitude, presenting great variability of solar radiation throughout the year. In spring-summer, the highest values of pumped volume were observed in the South region, as it presents higher numbers of hours of sun per day. In the autumn-winter, the Northeast region presented the highest values, and the South region the lowest because the days in this region are shorter in this season.

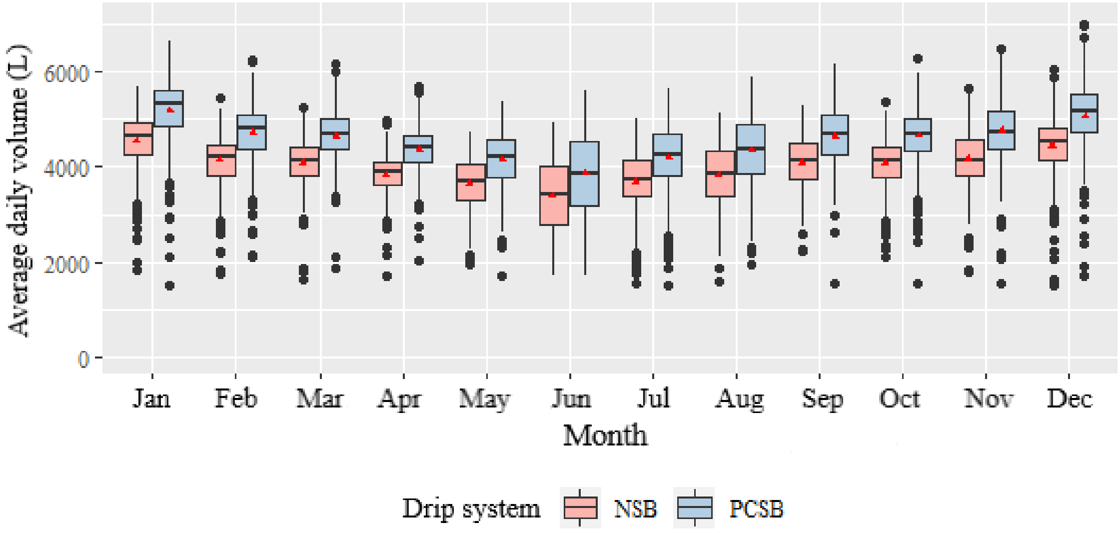
Campana *et al.* (2015) found that the use of photovoltaic energy for pumping in an irrigation system is an alternative for the supply of water in a sustainable and economically viable way, mainly for arid and semi-arid regions. Different scenarios must be tested about photovoltaic pumping to ensure the application efficiency and the supply of the irrigation depth required by the plants.

In Brazil, the Northeast presents a high potential for the use of photovoltaic pumping systems during the seasons. This region is characterized by relief uniformity and albedo, which favors high radiation values (FUNARI; TARIFA, 2017). Hassanien *et al.* (2016) concluded that photovoltaic energy is clean and inexpensive and may favor the development of small agricultural areas.

Some variations of this pattern were caused by the different atmospheric phenomena that predominate in each region at different times of the year. These phenomena are responsible for the seasonality of the rains, conferring different degrees of intensity and duration of rain, which also influences the length of the rainy and dry seasons.

In Figure 8 the boxplots of the daily average volumes pumped by all stations in each month are presented.

Figure 8. Boxplot average monthly volume pumped by the two systems.



A variation of about 20% was observed between the volume pumped into the drip without battery and with battery for the months of May to August, which are probably due to lower recorded radiation. This is because, for the equations used, there is a greater slope of the curve for smaller values of radiation. Thus, the South region due to the low values of solar radiation in this period will have small volumes pumped, while the Northeast region due to the smaller oscillation of the radiation, will present higher volumes pumped. During the summer months, although Brazil shows a higher solar radiation average, it is also very cloudy, due to the rainy season prevailing in the country, resulting in a large number of outliers. Besides, the average daily volume for Brazil has lower averages in autumn-winter and higher in spring-summer, since solar radiation is higher in the last season.

The average daily volume pumped for all stations evaluated ranged from 3396 to 4549 L for the NWB and from 3860 to

5189 L for the SCWB. The SCWB exceeded the volume pumped by the NWB system in an average of 556 L. This is because between 0.5 and 1.0 bar the self-compensating emitter has a higher flow rate compared to the normal emitter, according to the manufacturer's catalog. Thus, at times when there is low solar radiation, the SCWB has higher flow rates.

Also, at pressures greater than 1.0 bar the PC emitter must have practically constant flow, since the normal emitter must present an increase in flow with increasing pressure. However, this behavior was not observed for the PC emitter, and the visualization was easier in the B system, where the NB had an average pressure of 1.5 bar and average flow of each emitter of 4.9 L h^{-1}, the values were, respectively, 1.4 bar and 5.0 L h^{-1}.

For the same solar radiation condition, with WB system pumping water during the day while the B system recharged the batteries to later perform night pumping, we observed in Table 4 that the WB system pumped more than twice as much water. In addition, the test that evaluated the autonomy of the batteries by using the same hydraulic structure found an average volume of 2420.0 L pumped by the B system with the fully recharged batteries.

Table 4. Volume pumped by each system for the same solar radiation condition.

Volume WB (L)	Volume B (L)	Rate WB/ B
4983.4	2401.5	2.1
4562.6	2214.0	2.1
3719.6	1777.8	2.1
3980.5	1926.7	2.1
4494.0	2148.0	2.1
3840.0	1693.7	2.3

WB = no storage of energy in batteries and B = with storage of energy in batteries.

The WB system pumps more water because in system B energy losses occur due to the efficiency of the batteries not being 100% due to the losses in the conversion of the solar energy to the activation of the irrigation system. By analyzing the volume pumped by the B system in comparison with the volume pumped by the WB system. it is possible to affirm that in no day the solar radiation was enough to fully recharge the batteries, since the volume pumped by system B in no day reached the volume pumped by fully recharged batteries. Thus, the low volume pumped by system B can’t be justified by the full recharge of the batteries before the end of the day.

According to Michels *et al.* (2009), the flow of a photovoltaic pumping system is a function of the power generated by the panels and this is directly proportional to the increase of the solar radiation and inversely proportional to the increase of the panel temperature, although these relationships are not linear. Photovoltaic panels are tested under standard conditions, panel temperature of 25 ° C. In panel temperatures above this value, there is a decrease in the efficiency of the photovoltaic panels generating a lower power.

The photovoltaic system coupled to batteries can be an alternative to increase pumping efficiency, ensuring uniform application of the system along the entire lateral line. Chen et al. (2009) pointed out that the efficiency of stationary lead lithium batteries varies from 70 to 90%. Besides, losses can occur in the load controller. since it does not present 100% efficiency.

Joerissen *et al.* (2004), Zhang *et al.* (2017) and Hassan *et al.* (2017) point out that considering the demand for alternative energies, it is important that storage systems for renewable energies, such as solar, could be used to meet supply and demand. Seasonal variations of solar radiation should be considered when selecting the battery to suit the storage capacity and avoid problems with the discharge.

Photovoltaic systems for pumping in drip irrigation can be a viable technical and economical alternative. Reca *et al.* (2016) highlight that in areas where access to electricity is limited. photovoltaic systems can facilitate agricultural development. especially in small areas.

6 CONCLUSÃO

It is concluded that the use of a battery for the storage of the photovoltaic energy for the pumping of water in drip systems with normal and self-compensating emitters increases the uniformity of application of the flow of the drippers.

The largest volumes pumped throughout the year for drip systems with normal and self-compensating emitters without batteries occurred in the Northeast region of Brazil.

The photovoltaic system without energy storage pumped a larger volume of water than the system with batteries, however, the larger volume was not directly proportional to the uniformity of the system.

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