ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

PERFORMANCE DA IRRIGAÇÃO EM POLOS AGRÍCOLAS DO ESTADO DO CEARÁ

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1 RESUMO

O trabalho tem por objetivo avaliar a performance de sistemas irrigados nos seis principais polos agrícolas do Estado: DIBAU, DIPAN, DIJA, DISTAR, Serra da Ibiapaba e Cariri. Para tanto, estabeleceu-se avaliar de 10 a 16 áreas sob irrigação localizada em cada um dos polos. As informações coletadas em campo permitiram determinar os coeficientes de uniformidade de Christiansen (CUC), uniformidade de distribuição (CUD), uniformidade de pressão (CUP) e a eficiência de aplicação de água (Ea). Paralelamente, foi realizado o balanço hídrico anual em cada polo por meio da necessidade suplementar da cultura (NSC) e de irrigação (NSI). Observou-se que os sistemas irrigados nos polos apresentaram desempenho variando de "razoável" a "bom" segundo o CUC e CUD, porém, em todos eles, a Ea apresentou valores aquém do mínimo recomendado, sendo classificada como "inaceitável". Os polos do DIPAN e do DIJA foram os que apresentaram melhor e pior uniformidade de distribuição da água, respectivamente. Em todos os sistemas de irrigação, o balanço hídrico evidenciou a falta de manejo e controle da água, acarretando déficits e/ou excessos hídricos em relação à NSI.

Palavras-chave: recursos hídricos, manejo de irrigação, balanço hídrico.

VALNIR JÚNIOR, M.; ALMEIDA, C. L.; CARVALHO, C. M.; ROCHA, J. P. A.; GOMES FILHO, R.R.
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2 ABSTRACT

This work aims to evaluate the performance of irrigated systems in the six main agricultural centers of the state, DIBAU, DIPAN, DIJA, DISTAR, Serra da Ibiapaba and Cariri. To this end, 10 to 16 areas under irrigation located in each of the poles were evaluated. The information collected in the field made it possible to determine the Christiansen uniformity coefficient

Recebido em 07/05/2024 e aprovado para publicação em 10/12/2025
DOI: http://dx.doi.org/10.15809/irriga.2025v30p1-18

(CUC), distribution uniformity (CUD), pressure uniformity (CUP) and water application efficiency (Ea). Moreover, the annual water balance was carried out at each pole using the crop's water requirement (NSC) and irrigation (NSI). The performance of the irrigated systems at the poles ranged from "reasonable" to "good" according to the CUC and CUD; however, in all of them, the Ea presented values below the minimum recommended value and were classified as "unacceptable". The DIPAN and DIJA poles showed the best and worst uniformity of water distribution, respectively. In all the irrigation systems, the water balance revealed a lack of water management and control, resulting in water deficits and/or excesses in relation to the NSI.

Keywords: water resources, irrigation management, water balance.

3 INTRODUCTION

The state of Ceará, like others that make up the semiarid region of northeastern Brazil, is characterized by irregular rainfall patterns during the rainy season, which, combined with high evaporative demand, leads to water deficits for most months of the year, necessitating supplementary artificial recharge (Valnir Júnior *et al.,* 2010). Furthermore, the region is subject to at least one drought cycle per decade (Araújo; Bronstert, 2015; Pereira; Cuellar, 2015), with the last cycle observed between 2012 and 2016, resulting in significant losses for irrigated agriculture in the state (Silveira *et al.,* 2018).

Owing to the regional characteristics, agricultural activity can be considered to have low predictability and therefore high risk and low productivity (Araújo *et al.,* 2021). The main way to reduce the risks of the activity and increase productivity is through irrigation. The main water source used in the state's irrigated systems comes from reservoirs, which also serve human and industrial consumption (França *et al.,* 2018).

In addition, evaporation losses are significant given that the average annual evaporation exceeds 2,000 mm (Araújo; Bronstert, 2015). Thus, guaranteeing a water supply that ensures the maintenance of the system depends on two aspects: the first, independent of human intervention, consists of the natural regularity of rainfall in time and space; the second, entirely subject to human intervention, concerns the environmentally sound use of available water resources, especially irrigation, which is the greatest consumer.

The efficient and equitable use of water is of paramount importance given the region's limited water resources. Therefore, policies should be promoted that lead to well-designed, implemented, and managed irrigation systems (Ascough; Kiker, 2002). If not for the water itself, according to Kaneko *et al.* (2012) and Souza *et al.* (2019), irrigation associated with chemigation, in addition to potentially increasing productivity and product quality, also promotes cost reduction.

The efficiency of water and nutrient application to crops depends, among other factors, on the uniformity of distribution. The main means of evaluating irrigation systems are the water distribution uniformity coefficients, primarily the CUC and CUD, and the pressure coefficient, CUP, which can be obtained using the methodology of Keller and Karmeli (1975) and/or Denículi. *et al.* (1980).

However, even with guaranteed good levels of water distribution and application efficiency to plants by the systems, the need for management, whether it is water or determined by plants, climate, soil, or a combination thereof throughout the crop cycle, is highly necessary. Therefore, an irrigation system, even with good performance, if not associated with proper irrigation management, may not adequately meet a crop's needs and could lead to water deficit or excess. This is especially true in the latter case, as it not only contributes to decreased production but also increases the waste of this important resource.

Given the above, the objective of this work was to present an evaluation of irrigation performance in the main agricultural centers of the state of Ceará.

4 MATERIALS AND METHODS

The study was conducted in the six main irrigated agricultural production centers of the state of Ceará, four of which are located within irrigation districts and two within production regions. The irrigation districts evaluated were Araras Norte – DIPAN; Baixo Acaraú – DIBAU; Tabuleiro de Russas – DISTAR; and Jaguaribe Apodi – DIJA. The regions evaluated were Ibiapaba and Cariri. The assessments were conducted between 2021 and 2023.

4.1 Evaluation of irrigation systems

In each center, only the systems under localized microsprinkler and drip irrigation were evaluated, with ten areas analyzed in the Cariri region and 16 areas in each of the aforementioned centers. The number of samples was defined according to the methodology presented by Barbetta (2002).

The methodology used to collect flow and pressure values at the field level was that of Keller and Karmeli (1975). The performance of the irrigation systems was evaluated using the Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD), and water application efficiency (Ea), as presented by Saraiva, Rebouças and Souza (2014), as well as through the pressure uniformity coefficient (CUP) (Merrian; Keller, 1978). The performance classification of the irrigation systems is shown in Table 1.

Table 1. Performance classification of irrigation systems according to the Christiansen uniformity coefficient (CUC), distribution uniformity (CUD), pressure uniformity (CUP) and application efficiency (Ea).

Classification	CUC[1] (%)	CUD[1] (%)	Classification	CUP[1] (%)	Ea[2] (%)
Excellent	> 90	> 84	Ideal		> 95
Good	80 – 90	68 – 84			
Reasonable	70 – 80	52 – 68	Acceptable	≥ 80	80 – 95
Bad	60-70	36 – 52			
Unacceptable	< 60	< 36	Unacceptable	< 80	< 80

Source: [1] Mantovani (2001); [2] Bralts (1986)

4.2 Water balance

The water balance (WB) in each irrigation area was evaluated according to equations 1a and 1b, with a surplus considered when the WB was positive and a deficit considered when the WB was negative.

$BH = Pef - NSC$; if LA = 0 mm (1a)

or

$BH = (Pef + LA) - NSI$ if LA > 0 mm (1b)

where NSI is the supplemental irrigation requirement, mm; NSC is the supplemental crop requirement, mm; Pef is the effective rainfall, mm; and LA is the applied water depth, mm.

The NSI was determined according to equations 2, 3a and 3b (Valnir Júnior *et* *al.,* 2022). The applied blade (LA) was determined according to equation 4.

$$NSI = \frac{NSC}{Ef_{sistema\ irrigação}} \times 100 \quad (2)$$

$$NSC = ETc - Pef;\ se\ ETc > Pef \quad (3a)$$

or

$$NSC = 0;\ se\ ETc < Pef \quad (3b)$$

$$LA = \frac{Ti \times q_e \times Ne}{A_{pl}} \quad (4)$$

Where Ef is the irrigation system efficiency, dimensionless; ETc is the crop evapotranspiration, mm; Ti is the irrigation time, h; Ne is the number of emitters per plant, dimensionless; qe is the emitter flow rate, L h $^{-1}$; and Apl is the plant area, m².

All the irrigation systems evaluated integrate the localized irrigation method; therefore, the ETc used in equations 3a and 3b refers to crop evapotranspiration under localized systems (ETcloc), according to the methodology of Keller and Bliesner, as per equation 5 (Valnir Júnior *et al.*, 2022), which in turn is derived from equations 6 (Hargreaves; Samani, 1985) and 7, by Freeman and Garzoli (Frizzone). *et al.,* 2012).

$$ETcloc = ETo \times Kc \times Ks \times K_L \quad (5)$$

$$ETo=0,0023.Qo.(Tmáx-Tmín)^{0,5}.(Tméd+17,8) \quad (6)$$

$$K_L = Fc + 0,5(1 - Fc) \quad (7)$$

Where ETo is the reference evapotranspiration, mm; Kc is the dimensionless crop coefficient; Ks is the dimensionless water stress coefficient; K_L is the location coefficient; Tmax is the daily maximum temperature, °C; Tmin is the daily minimum temperature, °C; Tmed is the daily average temperature, °C; Qo is the extraterrestrial radiation at the top of the atmosphere, mm day $^{-1}$; and Fc is the soil cover factor, decimal.

In defining the crop coefficient, an average value was used between the phases of greatest demand (flowering/production) and the final phase (maturation) to avoid overestimating or underestimating the annual water demand of the crops, given the variability of crops and phenological stages observed in the evaluated areas and the reduced number of sampling units for some of the crops analyzed.

The water stress coefficient (Ks) was defined as 1 (one) since it is a high-frequency irrigation system with no apparent deficit. The location coefficient (K_L) was calculated according to equation 7; when the system was of the microsprinkler type, it varied according to the plant coverage area, with a minimum value of 33%; for drip irrigation systems, a value of 1.00 was adopted.

4.3 Irrigation planning consulted at the poles

Irrigation hubs exhibit distinct and unique characteristics with respect to irrigation planning.

In the DIPAN region, the Ibiapaba and Cariri regions suspend irrigation during the first half of the year (January to June) and become dependent on the rainy season for the water supply of the plants. This is even more crucial for the former, since the distribution of water to the district areas is performed collectively, and not taking advantage of natural rainfall greatly increases production costs because of pumping energy, potentially even making the entire activity unfeasible.

In the DIJA system, the flow rate available to irrigators in the second half of the year is 3.5 m³ s⁻¹, whereas in the first half, it is 1.5 $m^3\ s^{-1}$, meaning that irrigation practices in the first half of the year are reduced by 43%. In the DISTAR system, according to information collected from producers, on average, if rainfall exceeds 15 mm, irrigation is not carried out on that day. In the DIBAU system, this rainfall limit observed among producers was, on average, 10 mm.

4.4 Climate data collection and processing

Representative meteorological and precipitation data for each of the irrigation centers studied were obtained from stations located in or near the evaluated areas in conjunction with INMET and/or Funceme, as shown in Table 2. The water balance estimate used the average of years of records obtained from meteorological and rainfall stations.

Table 2. Meteorological and rainfall database for estimating the water balance in irrigation centers in the state of Ceará.

ID	Organ	Variables	Municipality	Pole	Period	Use[1]
A360	INMET	Temp.; Vv; UR	Acaraú	DIBAU	04/2009 – 12/21	Base
84	Funceme	P	Marco	DIBAU	04/2009 – 12/21	Base
2	Funceme	P	Acaraú	DIBAU	04/2009 – 12/21	Apoio
82392	INMET	Temp.; Vv; UR	Sobral	DIPAN	01/1988 – 03/20	Base
126	Funceme	P	Reriutaba	DIPAN	01/1988 – 03/20	Base
82588	INMET	Temp.; Vv; UR	Morada Nova	DIJA	01/1970 – 12/21	Base
124	Funceme	P	Quixeré	DIJA	01/1970 – 12/21	Base
82588	INMET	Temp.; Vv; UR; P	Morada Nova	DISTAR	01/2010 – 12/22	Base
62	Funceme	Temp.	Russas	DISTAR	04/2022 – 12/22	Apoio
127	Funceme	P	Morada Nova	DISTAR	01/2010 – 12/22	Apoio
A368	INMET	Temp.; Vv; UR;	Tianguá	Ibiapaba	03/2018 – 07/23	Base
35858	Funceme	Temp.	São Benedito	Ibiapaba	04/2022 – 07/23	Apoio
143	Funceme	P	Tianguá	Ibiapaba	03/2018 – 07/23	Base
132	Funceme	P	São Benedito	Ibiapaba	03/2018 – 07/23	Base
53	Funceme	P	Guaraciaba do Norte	Ibiapaba	03/2018 – 07/23	Base
82784	INMET	Temp.; Vv; UR; P	Barbalha	Cariri	01/2010 – 07/23	Base
A315	INMET	Temp.; Vv; UR; P	Barbalha	Cariri	01/2010 – 07/23	Apoio
35856	Funceme	Temp.	Missão Velha	Cariri	04/2022 – 07/23	Apoio
20	Funceme	P	Barbalha	Cariri	01/2010 – 07/23	Apoio
91	Funceme	P	Missão Velha	Cariri	01/2010 – 07/23	Apoio

[1] base – primary source of information; Support – used to fill in gaps. Temp. – average, maximum and minimum temperature; Vv – wind speed; UR – relative humidity; P – precipitation.
Source: Authors

5 RESULTS AND DISCUSSION

5.1 Evaluation of irrigation systems

The overall average assessment of irrigation in the state of Ceará indicated a "good" level of acceptability, with CUC and CUD values of 80.8% and 68.5%, respectively. However, Ea, with an average of 61.7%, was classified as "unacceptable". The operating pressure of the emitters was 110 kPa, with an average CUP of 89.1%, which was classified as "acceptable".

Table 3 presents a summary of the irrigation system situation in the irrigation hubs of the state of Ceará. The operating pressure (OP) was below the nominal pressure (NP) of most emitters in the evaluated systems. The OP was greater than or equal to the NP in only one area in the DIJA, DIPAN, and Ibiapaba irrigation hubs. In DIBAU, Cariri, and DISTAR, the percentages of systems with OP higher than NP were 37.5%, 36.3%, and 31.2%, respectively. The lowest OP occurred in the Ibiapaba region (Table 3) because 69% of the evaluated areas have drip irrigation systems. Thus, the hubs that presented the average OP furthest from the nominal pressure were DIJA, DIPAN, Ibiapaba, Cariri, and DISTAR. DIBAU was the only hub where the average OP corresponded to the nominal pressure, considering a reference value of 150 kPa.

The operating pressure directly affects the uniformity of water application, which in turn affects system efficiency (Ascough; Kiker, 2002; Rather; Ahmad Baba, 2018). Dwivedi and Pandya (2016) consider the operation of microsprinklers with pressures below 100 kPa undesirable, which was observed in four of the poles with microsprinklers (Table 3).

Table 3. Average values of service pressure (PS), Christiansen uniformity coefficient (CUC), distribution uniformity (CUD), pressure uniformity (CUP) and water application efficiency (Ea) and the percentage of areas classified as Good+ or Reg.- for CUC and CUD and Ac. or Inac. for the CUP and Ea of the irrigation systems evaluated in the main irrigation centers of the state of Ceará during the period from 2021 to 2023.

Poles		PS (kPa)	CUC (%)	CUD (%)	CUP (%)	Ea (%)	Irr. System³	
DIBAU	Average	152	85.6	74.5	91.0	67.1	Micro	100%
	Good+/Ac.[1]		81	69	88	6		
	Reg.-/Inac.[2]		19	31	12	94		
DIPAN	Average	97	90.0	83.1	92.5%	74.8	Micro	100%
	Good+/Ac.		100	94	100	38		
	Reg.-/Inac .		0	6	0	62		
DIJA	Average	100	42.8	8.1	100	7.31	Got .	6%
	Good+/Ac.		0	0	100	0		
	Reg.-/Inac .		100	100	0	100		
DIJA	Average	83	79.0	62.2	86.7	56.0	Micro	94%
	Good+/Ac.		47	40	87	7		
	Reg.-/Inac .		53	60	13	93		
DISSTAR	Average	141	75.4	60.7	86.2	54.6	Micro	100%
	Good+/Ac.		50	44	81	12		
	Reg.-/Inac .		50	56	19	88		
Ibiapaba	Average	80	78.1	59.7	89.5	53.7	Micro	31%
	Good+/Ac.		60	60	80	0		
	Reg.-/Inac .		40	40	20	100		
Ibiapaba	Average	71	87.7	80.4	94.7	72.4	Got .	69%
	Good+/Ac.		82	82	91	36		
	Reg.-/Inac .		18	18	9	64		
Cariri	Average	126	72.5	60.2	84.4	54.1	Micro	100%
	Good+/Ac.		55	45	82	9		
	Reg.-/Inac .		45	55	18	91		

[1] Percentage of areas evaluated with a good to excellent (Good+) rating for CUC and CUD and Acceptable (Ac.) for CUP and Ea; [2] percentage of areas evaluated with an unacceptable to regular (Reg.-) rating for CUC and CUD and unacceptable (Inac.) for CUP and Ea; [3] Irrigation system – Percentage of areas evaluated with drip irrigation (gray). and microsprinkler irrigation (Micro).
Source: Authors

As observed in Table 3, the irrigation hub that presented the best performance was DIPAN, in which 100% and 94% of the evaluated systems presented performance classified as excellent to good by CUC and CUD, respectively. This performance is corroborated by the lower pressure variation observed in CUP, in which 100% of the systems presented acceptable performance according to the classification observed in Table 1. DIPAN also had the highest percentage of irrigation systems classified as having an acceptable Ea (38%), followed by the Ibiapaba Hub, with 25% of the areas having an acceptable Ea.

Although DIPAN has an average PS below 100 kPa, it was the only evaluated area where the coefficient of use of public water (CUP) was classified as acceptable in 100% of the areas. This is due both to the collective irrigation system, which has well-dimensioned hydraulics, offering low pressure variability between systems, and to a strategy by irrigators to use emitters with higher flow rates. The average flow rate in DIPAN was 88.8 L $h^{-1,}$ which is 54% to 348% higher than that in the other irrigation areas evaluated. The higher flow rates are due mainly to the larger diameter of the emitter orifice, which reduces the risk of clogging and decreases the pressure variability within the irrigation system. These results are corroborated when the irrigation systems observed in Ibiapaba and DIJA are compared, where the performance of microirrigation with drip irrigation is better (Table 3).

The lowest irrigation system performance was observed in DIJA, followed by that in Cariri and DISTAR, whose performance was very similar. DIBAU, however, performed better than these, as even though it had less than 10% of its areas with Ea classified as unacceptable, it presented higher CUC and CUD.

Maroufpoor *et al.* (2010), when evaluating the irrigation systems of ten farms located in the Dehgolan Plain of Kurdistan Province, northwestern Iran, reported average CUC and CUD values of 66.5% and 51.0%, respectively, which classify the systems as reasonable to poor. Zamaniyan, Fatahi and Boroomand-Nasab (2014) also reported that microirrigation systems in Iran have low to poor performance, the main causes of which were inadequate operating pressure, emitter clogging and a lack of training for irrigators.

However, when evaluating three microsprinkler irrigated subunits in the São Gonçalo Irrigated Perimeter in the state of Paraíba, Brazil, Barreto Filho *et al*. (2000) concluded that although the PS (presumably referred to a specific irrigation level) was not in accordance with the technical specifications of the equipment, the systems presented high uniformity coefficients and a good efficiency index. This may partly explain the better performance of DIPAN (presumably referring to a specific irrigation system) even when the PS is below the recommended level.

5.2 Water balance

Table 4 presents a summary of the climatic variables of the six irrigation centers evaluated according to the data obtained from the meteorological and pluviometric stations shown in Table 2. The DIJA and DISTAR districts presented the greatest annual rainfall deficit (P – ETo), with values exceeding 1,150 mm $year^{-1\ and}$ a thermal amplitude (Tmax. – Tmin. greater than 11.5 °C. On the other hand, the Ibiapaba region presented the lowest annual rainfall deficit—145 mm $year^{-1}$—and a thermal amplitude of 9.1 °C.

Table 4. Climatic characterization of the six main irrigation centers in the state of Ceará.

Variables	Items.	DIBAU	DIPAN	DIJA	DISSTAR	Ibiapaba	Cariri
ETo (Hargreaves and Samani)	mm year $^{-1}$	1,707	1,878	1,899	1,933	1,476	1,915
Average rainfall	mm year $^{-1}$	1,190	890	720	749	1.331	1.058
Average annual maximum temperature	°C	32.9	34.3	34.0	34.2	28.5	33.2
Average annual temperature	°C	26.7	27.2	26.2	27.4	23.0	26.0
Average annual minimum temperature	°C	23.0	22.2	22.2	21.9	19.4	20.4
Average relative air humidity	%	75.9	68.5	71.4	71.7	78.6	73.5
Average wind speed	ms $^{-1}$	3.2	2.0	3.0	2.9	3.4	1.3

Source: Authors

The data obtained for determining ETc for the localized irrigation system and for each of the crops evaluated in the different centers are summarized in Table 5. The data were obtained in the field during the evaluations, such as crop and irrigation system spacing, as well as information gathered from specialized literature, such as the determination of the crop coefficient.

Table 5. Summary of the variables used in the calculation of crop evapotranspiration (ETc) for localized irrigation systems evaluated in the main irrigation centers of the state of Ceará during the period from 2021 to 2023.

Poles	Culture	N	Kc *	Ks	Apl (m²)	Dc (m)	As (m²)	Fc	K_L
DIBAU	Banana[1]	6	1.15	1.0	6.2	2.52	5.0	0.81	0.91
	Coco [6]	10	1.00	1.0	51.6	7.00	38.0	0.75	0.87
DIPAN	Banana[1]	13	1.15	1.0	6.8	2.52	5.0	0.74	0.87
	Papaya[1]	3	1.05	1.0	6.8	1.8	2.5	0.37	0.68
DIJA	Banana[1]	14	1.15	1.0	6.2	2.52	5.0	0.81	0.91
	Pitaya[3]	1	0.72	1.0	-	-	-	-	0.66
	Atemoya [4]	1	0.90	1.0	-	-	-	-	1.00 **
DISSTAR	Banana[1]	5	1.15	1.0	7.2	2.5	5.0	0.70	0.85
	Acerola[2]	2	1.05	1.0	20.0	4.0	12.6	0.63	0.81
	Guava[1]	4	0.80	1.0	34.3	4.5	15.9	0.46	0.73
	Pitaya[3]	1	0.72	1.0	7.0	-	-	-	0.66
	Passion fruit[1]	1	1.05	1.0	30.0	-	-	-	0.66
	Papaya[1]	1	1.05	1.0	5.5	1.8	2.5	0.46	0.73
	Grapes[1]	1	0.65	1.0	9.0	-	-	-	0.66
	Vegetables[1]	1	1.00	1.0	-	-	-	-	1.00
Ibiapaba	Bell pepper[1]	3	1.15	1.0	0.4	-	-	-	1.00 **

	Acerola[2]	4	1.05	1.0	19.2	4.4	15.0	0.78	0.89
	Tomato[1]	4	0.80	1.0	1.3				1.00 **
	Passion fruit[1]	2	0.72	1.0	6.8	-	-	-	1.00 **
	Strawberry [5]	1	1.05	1.0	0.9	-	-	-	1.00 **
	Avocado[1]	1	1.05	1.0	64.0	-	-	-	1.00 **
	Cabbage[1]	1	0.65	1.0	0.3	-	-	-	1.00
Cariri	Banana[1]	8	1.15	1.0	7.7	2.5	5.0	0.65	0.82
	Chuchu[1]	2	0.95 ***	1.0	24.0	-	-	-	0.66

N – number of areas evaluated; Kc – crop coefficient; Ks – moisture coefficient; K_L – location coefficient; Apl – plant area; Dc – coverage diameter; As – shaded area; and Fc – soil cover factor.
* The average Kc between the production and final phases was adopted so as not to underestimate or overestimate the annual water demand of the crops, since the crops present different phenological phases during the cycle. ** Drip irrigation system, which results in $K_L = 1.0$; *** The average Kc of the cucumber crop from the same family as chayote was used.
[1] Marouelli *et al.* (2011); [2] Paredes *et al.* (2024); [3] Divincula *et al.* (2019); [4] Simão (2004); [5] Bastos *et al.* (2013); and [6] Araújo *et al.* (2022).
Source: Authors

The water needs of crops, in general, in the six irrigation hubs during the first semester, were almost entirely met by the rainfall regime (Figure 1), with supplemental irrigation being necessary for two or three months (January, May, and June). During this period, even when the water demand was met by rainfall, irrigation was necessary to supply nutrients to the crops through fertigation. This was one of the reasons that justified irrigation during this period in DIBAU, DIJA, and DISTAR. However, it was observed that in all hubs, there is an urgent need to implement measures to evaluate irrigation management in production systems.

Considering an irrigation system with 100% efficiency, which would represent a Supplementary Irrigation Requirement (SIR) equal to the Supplementary Crop Requirement (SCR), it was observed that the SCR would not be met for only two months in the Ibiapaba (Figure 1E) and DIPAN (Figure 1B) regions and for one month in the Cariri region (Figure 1F). However, in Ibiapaba, this deficit occurred in the second half of the year, unlike in DIPAN and Cariri.

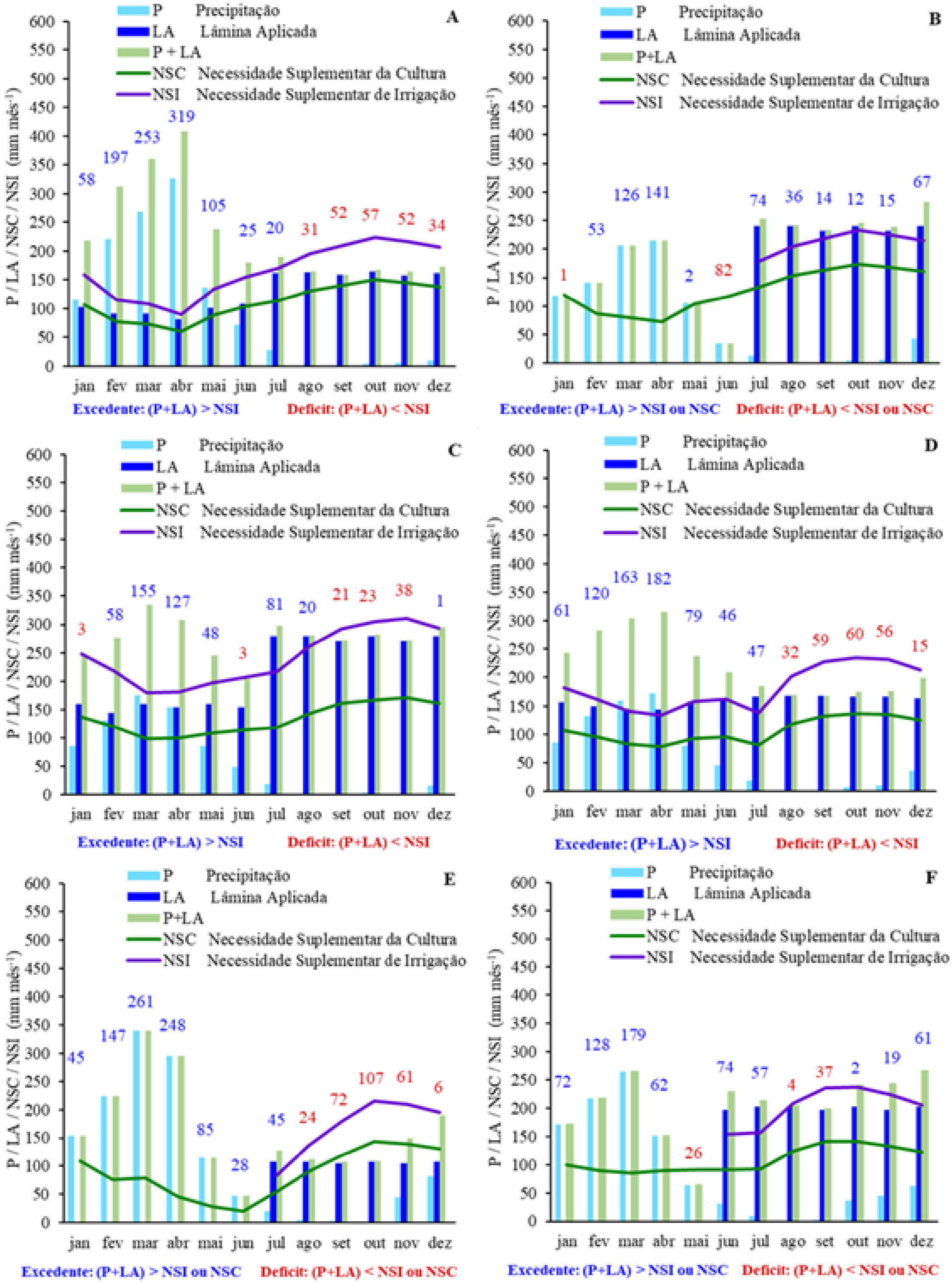
By analyzing the data presented in Figure 1 and considering the maintenance of the irrigation program currently in use, improved irrigation efficiency can be achieved with simple measures to resolve problems observed during irrigation system evaluations. Among these measures, the following can be highlighted: i) improvement of the filtration system; ii) ensuring that the emitters operate at nominal pressure, which is generally below nominal pressure; and iii) evaluations of the irrigation system every three or four months, with this evaluation being essential at the start of system use for areas irrigated only in the second half of the year; iv) correction of other problems observed in the evaluations, such as blockages, leaks, and low pressure; and v) standardizing the type of emitter in each sector, i.e., not using different emitters in the same sector.

It is important to highlight that within an irrigation system, altering one factor affects the others. For example, the filtration system affects the operating pressure, emitter clogging, irrigation uniformity, and production. When evaluating two filtration systems, Ribeiro *et al.* (2005) reported that the head loss could reach more than 100 kPa for a volume of 10 m^3 of filtered water. Compared with the disc filter, the nonwoven synthetic filter was more efficient, showing faster evolution of head loss as a function of the filtered volume and thus requiring a greater number of backwashes. These results corroborate the importance of irrigation management, since a reduction in head loss generally reduces the flow rate of the uncompensated emitter, and the lower removal of particles by the filter provides a greater risk of emitter clogging, which impacts system uniformity and production factors.

Liu *et al.* (2022) reported that the operating pressure is affected by the filtration system and that a decrease in pressure from 80 kPa to 40 kPa significantly reduced the average relative flow rate of the emitters, as well as the uniformity, since the decrease in the pressure differential promoted greater clogging of the emitters. These results corroborate Borssoi's findings. *et al.* (2012) and Dwivedi and Pandya (2016) reported that operating pressure influences irrigation system performance; low or high pressures contribute to reduced system uniformity. Furthermore, improving the irrigation system through a good filtration system also led to increased field productivity, as shown in the results presented by Lamskova. *et al.* (2021), who reported a 9% increase in productivity when a hydrocyclone system was used compared with a standard filtration system.

Furthermore, the hydraulics of the irrigation system are compromised by the use of emitters with different characteristics, not only in the same sector but also along the same lateral line, and by the removal of devices such as the diaphragm and the ballerina. These problems were observed in more than 60% of the areas in Cariri; in more than 40% of the areas in DIBAU, DIJA, and DISTAR; and in 12% of the areas in DIPAN and Ibiapaba.

Figure 1. Average annual water balance of the main irrigation centers in the state of Ceará. (A) DIBAU; (B) DIPAN; (C) DIJA; (D) DISTAR; (E) Ibiapaba; (F) Cariri.



Source: Authors

With the exception of DIPAN, in the other regions, the observed deficits in relation to the NSI could be minimized by increasing the efficiency of irrigation systems by adopting some of the measures suggested previously. The region that needs the greatest increase in application efficiency (Ea) of irrigated systems is Ibiapaba, which would require a 23% increase in Ea, as shown in Table 6. DIJA, on the other hand, would need only an 8% increase in Ea to meet the needs of supplementary irrigation.

However, achieving the NSI within the current system, i.e., with the same irrigation program, will still imply the application of excess water, since there will only be a downward shift of the NSI line in Figure 1, maintaining the same LA. Therefore, the implementation of irrigation management is necessary in all areas. In the more than 90 systems evaluated in this study, the absence of specialized technical assistance was observed, with only one area performing technical irrigation management, obtaining a CUD of 94.7% and a CUP of 100%, which could serve as an example for the other areas. Thus, a key factor in reducing the excess water applied would be the hiring of specialized personnel for the maintenance and management of the irrigation system.

According to the data in Table 6, the irrigation hub where rainfall accounted for the greatest share of the observed water surplus was the Ibiapaba region, with 88%, followed by DIBAU and DIPAN, with 47% and 42%, respectively. Conversely, the hub where rainwater represented the smallest share of the total surplus was DIJA (8%), followed by DISTAR and Cariri (15% and 38%, respectively). However, the surplus from rainwater cannot be controlled; rather, through management, this resource can be maximized to reduce irrigation.

Table 6. An evaluation of the application efficiency of the irrigation systems (Ea) at the six irrigation centers was performed, and the average monthly water depths were determined in terms of precipitation + applied depth (P+LA), the supplementary needs of the crop (NSC) and irrigation (NSI), and the total depth surplus (Exc. Total) and that promoted only by precipitation (Exc. P) and by irrigation (Exc.LA).

Poles	Ea current	Ea (NSI)[1]	ΔEa	(P+LA)	NSC	NSI	Exc . Total	Exc . P		Exc . LA	
	(%)			mm month $^{-1}$				mm month $^{-1}$	(%)	mm month $^{-1}$	(%)
	THE	B	(AB)	W	D	AND	F = (CD)	G	H = (G/F)	I = (FG)	J = (I/D)
DIBAU	67	90	23	228	111	165	117	55	47	62	56%
DIPAN[2]	75	75	0	193	128	213	65	27	42	38	30%
DIJA	55	63	8	276	133	242	143	12	8	131	98%
DISSTAR	58	79	21	222	106	182	116	17	15	99	93%
Ibiapaba[2]	67	94	27	164	87	170	77	68	88	9	11%
Cariri[2]	60	71	11	205	108	203	97	37	38	60	55%

[1] Efficiency value that the hub must achieve to meet the NSI demand; [2] Irrigation occurs only in the second half of the year, from June to December (Cariri) and July to December (Ibiapaba).
Source: Authors

The ratio between the surplus generated solely by the applied water depth and the NSC (Table 6, column J) is important information, as it more coherently reflects the region that performs the best water resource management. In this respect, Ibiapaba and DIPAN stand out, presenting the lowest percentages of 11% and 30%, respectively. However, the lower value observed in Ibiapaba should be analyzed carefully, considering that during the second month, when the water demand of the crops was essentially met by irrigation, the water supply (P+LA) was below the NSC (Figure 1E). These results corroborated the evaluation of the systems, in which the best performance was also observed in DIPAN.

6 CONCLUSION

All the irrigation systems evaluated in the different irrigation centers presented low performance indices and/or were below the minimum recommended for the localized irrigation method. The reasons for this unsatisfactory performance are diverse, ranging from negligence in operation and maintenance, such as filter cleaning, leak repair, emitter clogging, and lack of periodic system evaluations, to hydraulic causes such as the occurrence of emitters with different flow rates in the same line and/or irrigation unit, operating pressures incompatible with the emitter demand, and even flaws in system construction, and, no less importantly and certainly worrying, the almost total, if not total, lack of knowledge among producers regarding basic water management and control strategies, resulting in applications that are often excessive and sometimes insufficient.

7 ACKNOWLEDGEMENTS

Acknowledgments to the Chief Scientist in Agriculture Program of the Government of the State of Ceará, Agreement 14/2022 SDE/ADECE/FUNCAP and Process 08126425/2020/FUNCAP, for granting innovation scholarships and financial support for the research; to the Federal Institute of Education, Science and Technology – Sobral Campus; to the management of the Irrigation Districts Araras Norte – DIPAN; Baixo Acaraú – DIBAU; Tabuleiro de Russas – DISTAR; Jaguaribe Apodi – DIJA; to the Municipal Secretariats of Agriculture of the municipalities involved in the Serra da Ibiapaba and Cariri regions of Ceará; and to the COGERH Regional Management of Limoeiro do Norte, for the receptiveness to the project and the unconditional logistical support provided.

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