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Irrigation demand of economically significant crops in the Araras Norte and Baixo Acaraú districts, Ceará, Brazil

Demanda de irrigação de culturas de expressão econômica nos distritos Araras Norte e Baixo Acaraú, Ceará, Brasil

Demanda de riego de cultivos económicamente importantes en los distritos de Araras Norte y Baixo Acaraú, Ceará, Brasil

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Abstract
The aim of this study was to analyze the water demand in banana, papaya and coconut crops grown in the irrigation districts of Araras Norte and Baixo Acaraú, located in the State of Ceará. A historical meteorological series of the regions where the irrigation districts from this study are located was used. Precipitation, maximum and minimum temperatures, and relative humidity data were obtained from these historical series. From the acquired precipitation data, to analyze the frequency and intensity of dry and rainy years in the area, the Rainfall Anomaly Index was calculated. Based on the meteorological data from the historical series, the reference evapotranspiration by the Hargreaves-Samani method and the crop evapotranspiration were determined. The crop water requirement was obtained based on crop evapotranspiration and precipitation. In the plots, irrigation systems were evaluated and the application efficiency was determined in order to obtain the supplementary irrigation requirement. The irrigation depths used in the Araras Norte and Baixo Acaraú irrigation districts were underestimated, not meeting the supplementary irrigation requirement. For banana and papaya crops in the Araras Norte irrigation district, performing irrigation in the first semester and applying irrigation management throughout the year could correct the water deficit. For banana and coconut crops in the Baixo Acaraú irrigation district, it would be necessary to correct the irrigation depth in the second semester, through adequate irrigation management, because in the first semester precipitation would be sufficient to meet the crop water requirement.
Keywords: Banana; Papaya; Coconut; Crop water requirement.

Resumo
O objetivo deste estudo foi analisar a demanda hídrica nas culturas da banana, mamão e coco cultivadas nos distritos de irrigação Araras Norte e Baixo Acaraú, localizados no Estado do Ceará. Foi utilizada uma série histórica meteorológica das regiões onde estão implantados os distritos de irrigação oriundos deste estudo. Nestas séries foram obtidos dados de precipitação, temperaturas máxima e mínima e umidade relativa do ar. A partir dos dados de precipitação adquiridos, para analisar a frequência e intensidade dos anos secos e chuvosos na área foi calculado o Índice de Anomalias de Chuvas. Com base nos dados meteorológicos das séries históricas foi determinada a evapotranspiração de referência pelo método de Hargreaves-Samani e a evapotranspiração da cultura. A necessidade suplementar da cultura foi obtida com base na evapotranspiração da cultura e na precipitação. Nos lotes foram realizadas avaliações dos sistemas de irrigação e determinada a eficiência de aplicação para obtenção da necessidade suplementar de irrigação. As lâminas de irrigação utilizadas nos distritos de irrigação Araras Norte e Baixo Acaraú foram subestimadas, não atendendo a necessidade suplementar de irrigação. Para as culturas da banana e mamão no distrito de irrigação Araras Norte, a realização da irrigação no primeiro semestre e aplicação do manejo da irrigação ao longo do ano poderiam corrigir o déficit hídrico. Para as culturas da banana e do coco no distrito de irrigação Baixo Acaraú, seria necessária uma correção das lâminas aplicadas no segundo semestre, através de um manejo de irrigação adequado, porque no primeiro semestre a precipitação seria suficiente para atender a demanda hídrica das culturas.
Palavras-chave: Banana; Mamão; Coco; Necessidade hídrica da cultura.

Resumen
El objetivo de este estudio fue analizar la demanda de agua en los cultivos de plátano, papaya y coco cultivados en los distritos de riego de Araras Norte y Baixo Acaraú, ubicados en el Estado de Ceará. Se utilizó una serie meteorológica histórica de las regiones donde se encuentran los distritos de riego de este estudio. De estas series históricas se obtuvieron datos de precipitación, temperaturas máximas y mínimas y humedad relativa. A partir de los datos de precipitación adquiridos, para analizar la frecuencia e intensidad de los años secos y lluviosos en la zona, se calculó el Índice de Anomalía Pluvial. A partir de los datos meteorológicos de las series históricas, se determinó la evapotranspiración de referencia por el método de Hargreaves-Samani y la evapotranspiración de los cultivos. Las necesidades hídricas de los cultivos se obtuvieron a partir de la evapotranspiración de los cultivos y de las precipitaciones. En las parcelas se evaluaron los sistemas de riego y se determinó la eficacia de la aplicación para obtener las necesidades de riego suplementario. Las profundidades de riego utilizadas en los distritos de riego de Araras Norte y Baixo Acaraú fueron subestimadas, no cumpliendo con el requerimiento de riego suplementario. Para los cultivos de plátano y papaya en el distrito de riego de Araras Norte, la realización del riego en el primer semestre y la aplicación del manejo del riego a lo largo del año podrían corregir el déficit hídrico. Para los cultivos de plátano y coco en el distrito de riego del Bajo Acaraú, sería necesario corregir la profundidad de riego en el segundo semestre, mediante una gestión adecuada del riego, ya que en el primer semestre las precipitaciones serían suficientes para satisfacer las necesidades hídricas de los cultivos.
Palabras clave: Plátano; Papaya; Coco; Necesidad de agua de los cultivos.

1. Introduction

Brazilian irrigated agriculture, which is highly intensive in the use of water resources, represents about 70% of the water consumed (ANA, 2021), making it necessary to adequately quantify the crop water requirement.

In the case of the Brazilian Northeast, particularly in the semi-arid region, water use is an important issue when it refers to its social development. However, the awareness of the rational use of water, by means of adequate management, is still a problem, mainly due to the lack of planning and management of water resources, added to the scarcity of precipitation and high evapotranspiration, which directly affects the production of food (Cruz, et al., 2016).

Climate change scenarios point to a reduction in rainfall and an increase in seasonality in many regions of the world, which may affect the hydrological regime and increase the expansion of arid and semiarid areas (Huang, et al., 2016; Kang, et al., 2017).

Agricultural water management faces challenges with water scarcity issues, land resource pressure, and climate change, and there are uncertainties among the various activities in agricultural water management systems (Davijani, et al., 2016; Hu, et al., 2016; Xie, et al., 2018).

The Araras Norte and Baixo Acaraú irrigation districts, despite the use of drip and micro-sprinkler irrigation systems that provide high efficiencies, do not perform irrigation management properly, promoting great waste in water application, as in many other irrigation districts in Northeastern Brazil.

Both water deficit and excess, both supply situations promote decreases in crop productivity, conditioning them to low yields, causing discouragement to the activity as a whole and often resulting in the forced displacement of farming families to the outskirts of large cities.

Knowledge of the water demand of any crop is of great importance for proper development and planning. The correct water supply not only favors the quality of the product, but also the rational use of water, increasing the efficiency of its use, especially those located in arid and semiarid regions (Levidow, et al., 2014).

The crop water consumption is based on the estimation of crop evapotranspiration, which is one of the most used methods for irrigation management, due to high correlations between crop coefficient and phenological development of the crop. In addition, using crop evapotranspiration can facilitate better irrigation planning and water use efficiency (Rozenstein, et al., 2018).

Thus, the estimation of crop water requirements, at different stages of development, is decisive for planning and adequate water management in irrigated agriculture (Tomazetti, et al., 2015) and water balance estimation is an important tool to assess the current state and it's tendency of water resources availability in a given region over a period of time (Silva, et al., 2017).

Therefore, the aim of this study was to analyze the water demand in banana, papaya and coconut crops grown in the Araras Norte and Baixo Acaraú irrigation districts.

2. Methodology

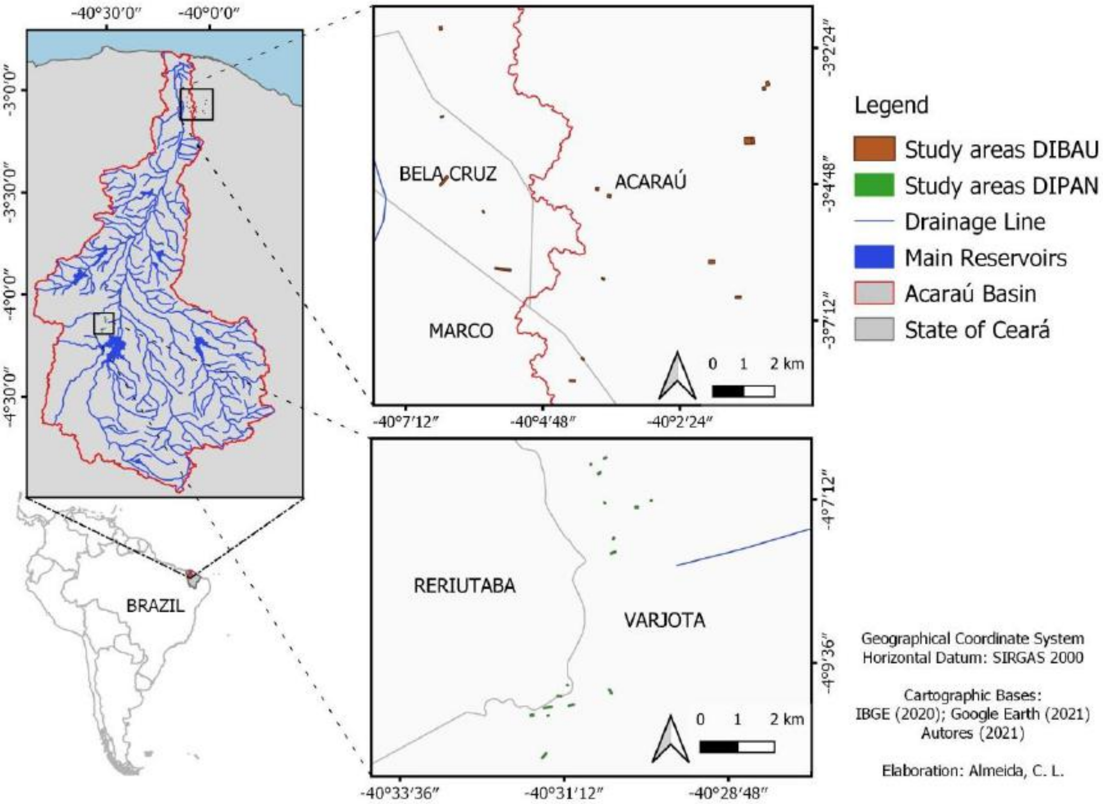
The study was carried out in the Araras Norte Irrigation Districts (DIPAN) and Baixo Acaraú Irrigation Districts (DIBAU), located in the watershed of the Acaraú River, in the state of Ceará, Brazil.

Irrigation plots were selected for the study and for the sample sizing, all elements of the finite population were considered with the same non-zero probability of being selected to compose the sample. It was considered a sampling error (d) of 20% with a standard deviation (Z) of 1.645 in a population of 241 and 86 plots of farmers (N) of DIPAN and DIBAU, respectively and with the percentages of the favorable (p) and unfavorable (q) sample elements of 50% for each. The sample size (n) was determined by equation (1) presented by Fonseca and Martins (2011).

$$n = \frac{Z^2 pqN}{d^2 (N-1) + Z^2 pq} \quad (1)$$

Using the data for each variable in the above equation (1), 16 farmers plots were selected in both DIPAN and DIBAU. The distributions of the plots in the Araras Norte and Baixo Acaraú irrigation districts can be seen in Figure 1.

Figure 1. Location map of the Araras Norte and Baixo Acaraú irrigation districts and the selected plots of each area.



Source: Authors.

Thirteen plots of land were cultivated with banana and three plots with papaya in DIPAN and 10 plots were cultivated with coconut and 6 plots were cultivated with banana in DIBAU. Crops that occupied more than 50% of the cultivated area in each irrigation district were considered expression crops.

The climatic characterization of the regions of the Araras Norte and Baixo Acaraú irrigation districts, as described by Köppen, is of BSwh' type, corresponding to a semi-arid region, with a rainy season from January to May, average annual precipitation rates of less than 900 and 1200 mm for DIPAN and DIBAU, respectively, with irregular distribution and average temperatures ranging between 25 and 28 °C in DIPAN and 26 to 29 ºC (Table 1).

Table 1. Monthly averages of climate characteristics for the periods 1995 to 2019 and 2009 to 2021 for the Araras Norte and Baixo Acaraú irrigation districts, respectively.

Araras Norte irrigation district (DIPAN)[1]				
Months	Precipitation (mm)	Maximum temperature (ºC)	Minimum temperature (ºC)	Relative humidity (%)
January	118.6	34.17	22.99	70.8
February	140.4	32.70	22.68	78.5
March	206.6	32.07	22.64	83.0
April	214.3	31.43	22.57	84.6
May	105.7	32.15	22.09	80.6
June	35.3	32.96	21.12	72.3
July	12.9	34.09	20.90	67.5
August	1.0	35.81	21.11	58.6
September	0.4	36.70	21.92	57.9
October	5.2	36.88	22.42	56.4
November	6.9	36.67	22.59	57.5
December	42.5	36.16	22.92	65.3
Baixo Acaraú irrigation district (DIBAU)[2]				
Months	Precipitation (mm)	Maximum temperature (ºC)	Minimum temperature (ºC)	Relative humidity (%)
January	115.4	32.61	23.40	53.0
February	220.8	31.81	23.38	61.2
March	268.7	31.43	23.22	62.4
April	326.8	30.98	23.13	66.1
May	136.5	31.45	23.04	61.4
June	71.7	32.18	22.54	50.6
July	28.2	32.96	22.46	42.9
August	1.3	34.13	22.62	36.0
September	0.1	34.53	22.87	35.6
October	3.7	34.48	23.02	38.0
November	6.1	34.30	23.06	40.1
December	10.4	33.84	23.28	43.5

[1] Source: Precipitations obtained from Reriutaba Post (Id: 126, Funceme) period 1995 to 2019; Temperatures and Relative Humidity obtained from Sobral station (id: 82392, INMET), period 1995 to 2019; [2] Source: Precipitation obtained from Marco Posto (Id: 84, Funceme) for the period 2009 to 2021; Temperatures and Relative Humidity obtained from Acaraú station (id: A360, INMET), for the period 2009 to 2021. Source: Authors.

Historical series of daily climate data obtained from the National Institute of Meteorology and the Ceará Meteorology and Water Resources Foundation, comprising 24 years (1995 to 2019) and 13 years (2009 to 2021), respectively for DIPAN and DIBAU, were used to estimate daily values of precipitation (P), reference evapotranspiration (ETo), crop evapotranspiration (ETc), crop water requirement (CWR), and supplemental irrigation requirement (SIR). Periods with missing or inconsistent data were disregarded.

From the acquired precipitation data, to analyze the frequency and intensity of dry and rainy years in the area, the Rainfall Anomaly Index (RAI) was calculated. This index considers the classification of precipitation values to calculate the anomalies, considering them positive or negative. In this way, depending on the calculated value the regime can be classified from extremely dry to extremely rainy, which helps to monitor and define years of mild to excessive drought or precipitation (Hänsel, et al., 2016).

The RAI is used to monitor the precipitation regime for agricultural planning in irrigated areas. The positive or negative RAI is defined by the condition, such that if the assessed precipitation is greater than the annual average of the historical series, the positive RAI formula is used, but if the assessed precipitation is less than the annual average of the historical series, the negative RAI formula is used. The index is calculated by equations 2 and 3.

$$RAI_{positive} = 3 \; x \left[\frac{(N - N_1)}{(M - N_1)}\right] \quad (2)$$

$$RAI_{negative} = -3 \; x \left[\frac{(M - N_1)}{(X - N_1)}\right] \quad (3)$$

where: N = observed precipitation of the year in which the RAI will be generated (mm); N1 = average annual precipitation of the historical series (mm); M = average of the ten largest annual precipitation of the historical series (mm) and X = average of the ten smallest annual precipitation of the historical series (mm).

The Rainfall Anomaly Index classification was performed according to the parameters in Table 2.

Table 2. Classification of the Rainfall Anomaly Index (RAI).

	RAI range	Intensity class
Rainfall Anomaly Index (*RAI*)	>4	Extremely humid
	2 a 4	Very humid
	0 a 2	Wet
	-2 a 0	Dry
	-4 a -2	Very Dry
	<-4	Extremely dry

Source: Authors.

In the Araras Norte Irrigation District, from February to June, water replacement is only due to natural recharges (electric shutoff for collective pumping), in the other months irrigation is carried out, with daily supplies available from 3:00 a.m. to 11:00 a.m. Due to the limited time available for irrigation, the use of high flow emitters was unanimously in the District, with average of 88.7 L h^{-1}, resulting in wasted water.

To estimate reference evapotranspiration the Hargreaves-Samani method was used (equation 4), which requires only information on minimum and maximum temperature and solar radiation. During the day, depending on the amount of clouds in the sky, high temperatures are offered allowing the entry of solar radiation, while at night temperatures are lower and the incidence is also small.

$$\mathrm{ETo} = 0{,}0023\mathrm{x}Q_0\,(\mathrm{Tmáx} - \mathrm{Tmín})^{0{,}5}(17{,}8 + \mathrm{T}) \quad (4)$$

where: ETo -Reference evapotranspiration (mm day^{-1}); Tmin- minimum temperature (°C); Tmax- maximum temperature (°C); T- average temperature (°C); Q_0- solar radiation at the top of the atmosphere (mm day^{-1}).

The application of the equation by Hargreaves and Samani (1985) is an affordable choice for the assessment of reference evapotranspiration, at a tima when there are not enough climatic data to use the Penman-Monteith method (Lima Junior, et al., 2016).

The crop evapotranspiration (ETc) was calculated for each day of the year, according to the methodology of Keller and Bliesner (1990), using equation 5, with Ks values equal to 1, because it is localized irrigation, and Kl also equal to 1, because the area is 100% shaded. We adopted Kc equal to 1.15 for banana (Doorenbos & Kassam, 1994; Oliveira, et al. 2005), 0.92 for papaya (Allen, et al. 1998) and 1 for coconut (Miranda & Gomes, 2006), recommended for conditions of full establishment of the crop.

$$ETc_i = Kc_i \; x \; Ks_i \; x \; Kl \; x \; ETo_i \tag{5}$$

where: ETc_i - crop evapotranspiration on day *i*, mm; ETo_i - reference evapotranspiration on day *i*, mm; Kc_i - crop coefficient on day *i*, dimensionless; Ks_i - soil moisture coefficient on day *i*, dimensionless; Kl - location coefficient, dimensionless.

The crop water requirement (CWR), considering the contribution of rainfall, was obtained by equations 6 and 7.

$$CWR_i = ETc_i - P_i, se \; ETc_i > P_i \tag{6}$$

$$CWR_i = 0, se \; ETc_i < P_i \tag{7}$$

where: $CWRi$ - crop water requirement on day *i*, mm; P_i - precipitation on day *i*, mm.

The supplemental irrigation requirement guarantees that all plants will receive a water depth greater than or equal to the necessary to supply the water deficit, calculated using equation 8 and adopting an irrigation efficiency equal to the value obtained in loco in each plot in the Araras Norte and Baixo Acaraú Irrigation Districts, based on the evaluations done in the banana, papaya and coconut crops.

$$SIR_i = \frac{CWR_i}{E_a} \tag{8}$$

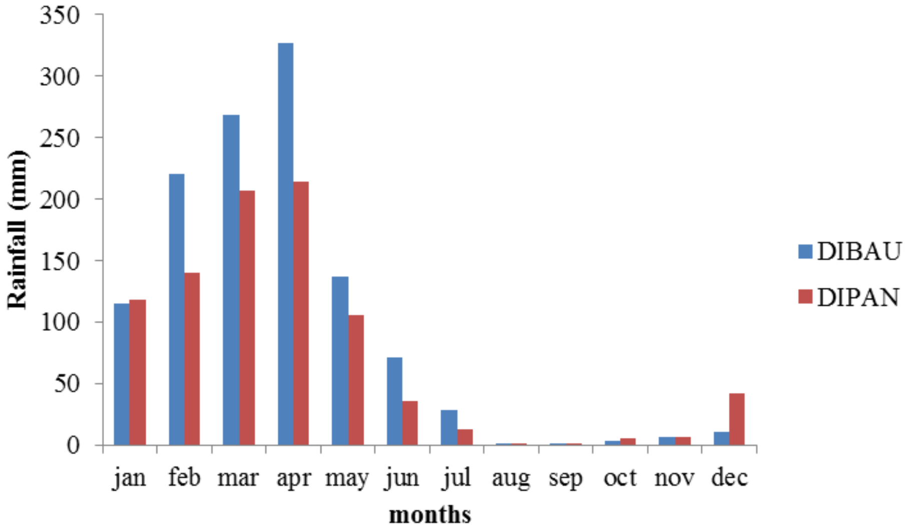
where: SIR_i - supplemental irrigation requirement on day *i*, mm and E_a - irrigation system efficiency, %.

3. Results and Discussion

Climate Analysis and Rainfall Anomaly Index (RAI)

The monthly precipitation averages for the Araras Norte (DIPAN) and Baixo Acaraú (DIBAU) Irrigation Districts, based on the historical precipitation series of the regions studied, can be seen in Figure 2.

Figure 2. Monthly precipitation averages in the Araras Norte and Baixo Acaraú irrigation districts.



Source: Authors.

It was possible to observe an irregular distribution of precipitation throughout the year, implying the need for irrigation in agricultural crops of these regions.

In order to justify the absence or reduction of precipitation data, the classification and analysis of the rainfall anomaly index (RAI) was performed for the Araras Norte and Baixo Acaraú Irrigation Districts for the analyzed period.

The results of the rainfall anomaly index analysis for each month in the studied period from 1995 to 2019 for the DIPAN region and for the period from 2009 to 2021 for DIBAU region have been described in Table 3.

Table 3. Quantification of the months of occurrence of Rainfall Anomaly Index (RAI) respective to the qualification for each month in the studied period from1995 to 2019 for the DIPAN region and for the period from 2009 to 2021 for DIBAU region.

DIPAN												
Classification	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Extremely dry	0	0	0	0	0	24	26	31	33	31	27	21
Very dry	21	19	17	20	16	0	1	0	0	0	0	0
Dry	0	0	0	2	0	0	0	0	0	0	0	1
Wet	8	8	10	8	11	6	1	0	0	1	4	3
Very humid	1	5	4	1	5	0	3	1	0	0	1	6
Extremely wet	4	2	3	3	2	4	2	2	1	2	2	3
DIBAU												
Classification	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Extremely dry	0	0	0	0	0	0	0	0	0	0	0	0
Very dry	9	2	7	0	0	8	0	0	0	0	0	0
Dry	0	7	0	8	9	0	8	10	12	11	11	10
Wet	0	0	3	0	0	0	1	0	0	1	0	0
Very humid	4	0	0	1	0	2	1	0	0	0	0	0
Extremely wet	0	4	3	4	4	3	3	3	1	1	2	3

Source: Authors.

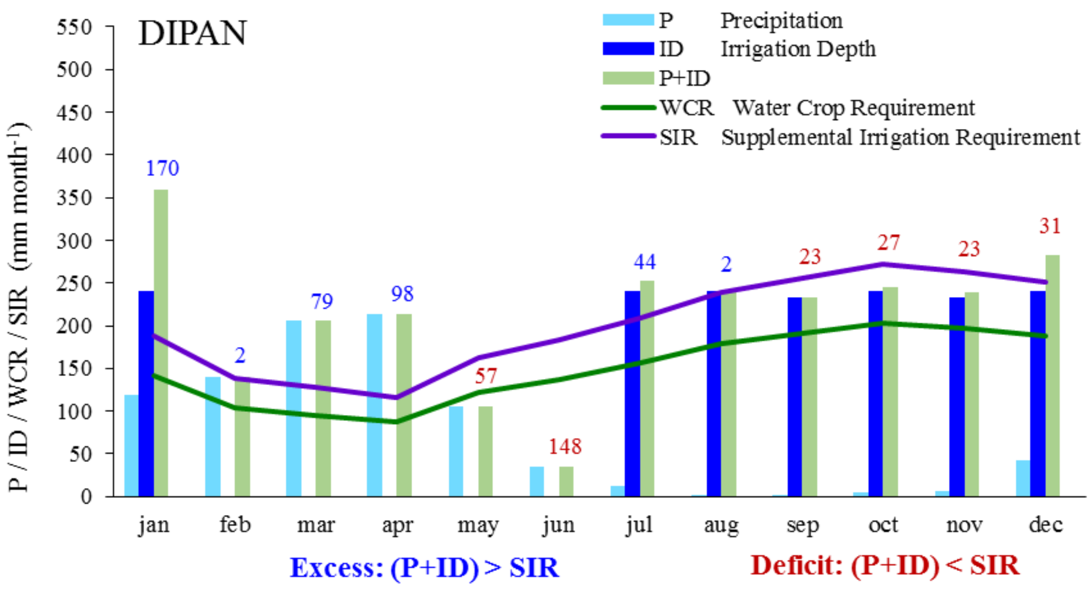
Considering the Rainfall Anomaly Index (RAI) for each month, in these series for DIPAN in the months of June to December, one could observe the occurrence of extremely dry periods, ranging from 62 to 97%, while in the months of January to May the occurrence of dry periods, ranging from 47 to 62%. It was possible to identify that the rainy period in the region was from January to May (Figure 1), in which the occurrence of the wet period corresponded from 25 to 33%.

For the historical series studied at DIBAU, it was possible to observe a greater occurrence of dry and very dry periods corresponding to all months of the year. The rainy period was observed in the months from January to May (Figure 1), similarly to what occurred in DIPAN.

Water demand in the Araras Norte and Baixo Acaraú Irrigation Districts

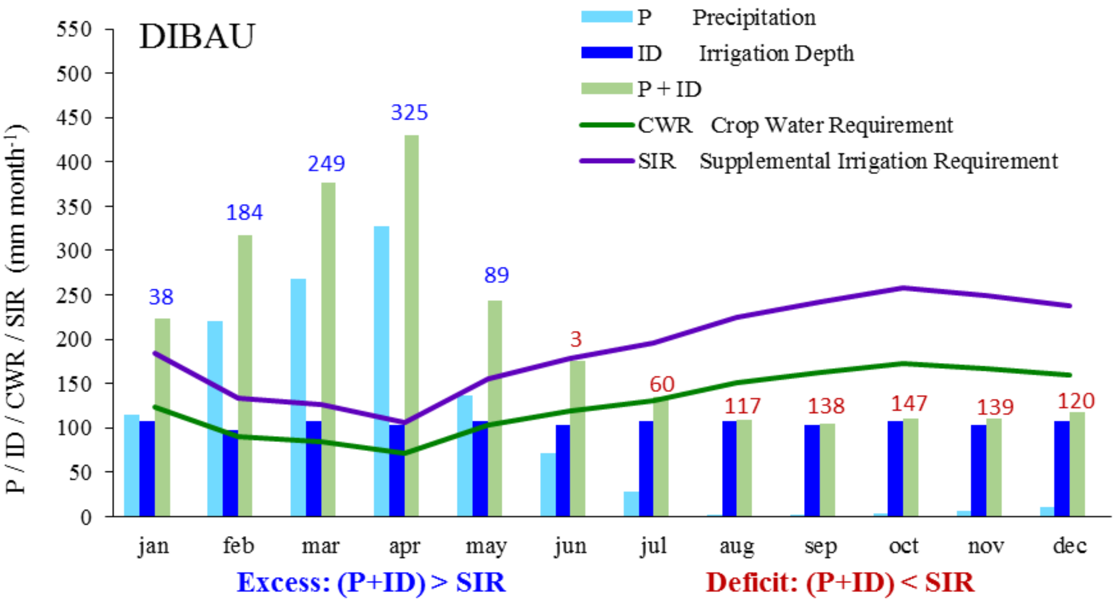
The comparison of water demand for applied values with estimated values was performed in the Araras Norte (Figure 3) and Baixo Acaraú (Figure 4) Irrigation Districts.

Figure 3. Irrigation demand and water balance of the Araras Norte Irrigation District (DIPAN).



Source: Authors.

Figure 4. Irrigation demand and water balance of the Baixo Acaraú Irrigation District (DIBAU).



Source: Authors.

Analyzing the situation in DIPAN (Figure 2), irrigation only took place from July to January, but in the months of September, October, and November, the irrigation depths were insufficient to meet the crop water requirement in DIPAN. Despite this situation, an annual surplus of 148 mm was observed, with uneven distribution. The need to program irrigation management was verified, because in the months of January and July, the applied irrigation depths overestimated the values necessary to supply the crop water requirement, promoting a waste of water.

May and June are the most critical months and generate a deficit of 205 mm, while January, March, and April represent 82.2% (347 mm) of the excess volume.

Observing October, the month of greatest deficit under irrigation, if the supplementary irrigation requirement (SIR) were equal to the sum of precipitation and the irrigation depth applied (P+LA), an increase of 8.2% in efficiency (83%) and a reduction in the irrigation water requirement could be obtained, generating a surplus water production of 102 mm, which would be sufficient to meet the deficit of 75 mm of August through November. If you consider the whole period with irrigation the water reserve would be 166.3 mm or 1,663 m^3 ha^{-1}.

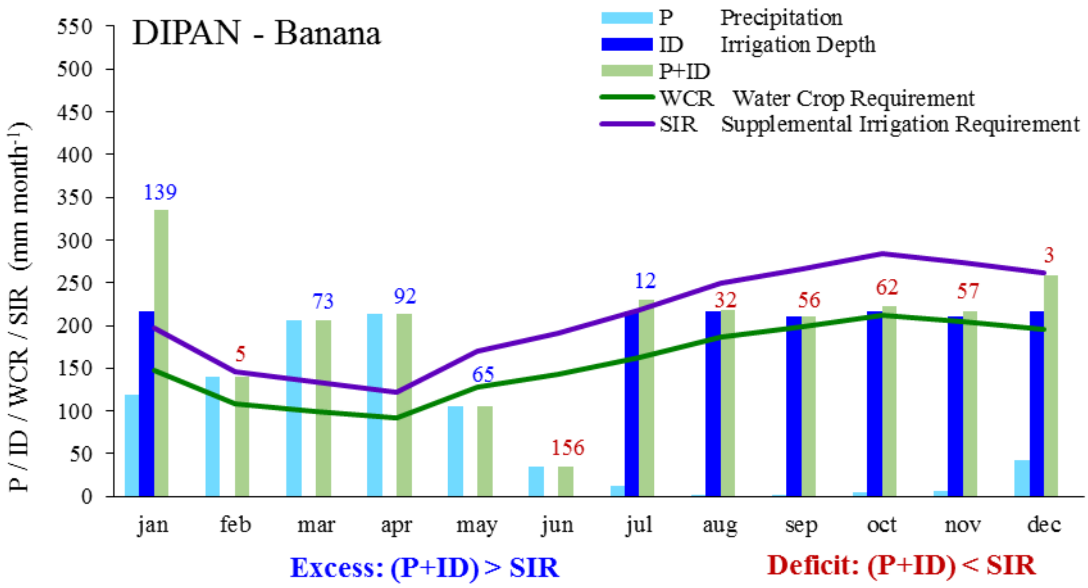
Analyzing the situation of DIBAU (Figure 3), even with irrigation being performed every month, a water deficit of 724 mm was observed from June to December, with a water surplus only occurring in the months of highest precipitation, January to May, guaranteeing full recharge. Regarding the water supply to the crops through irrigation, it was found that, in all months of the year, the applied irrigation depths were deficient and did not meet the monthly water supply demanded by the crop.

Water Demand of expression crops in the Araras Norte and Baixo Acaraú Irrigation Districts

Comparative studies of observed and estimated water demands were carried out for banana and papaya crops in DIPAN and banana and coconut crops in DIBAU in the period corresponding to the historical series studied.

The crop water requirement (CWR) of banana in DIPAN was 1724.10 mm, but with the application of water by irrigation, for the irrigation system used in DIPAN, the supplemental irrigation requirement (SIR) throughout the cycle was 2535.50 mm, providing a water application efficiency of 67.9%, far below what the micro-sprinkler irrigation system can provide for more efficient irrigation (Figure 5).

Figure 5. Irrigation demand and water balance for banana crop produced in the North Araras Irrigation District (DIPAN).



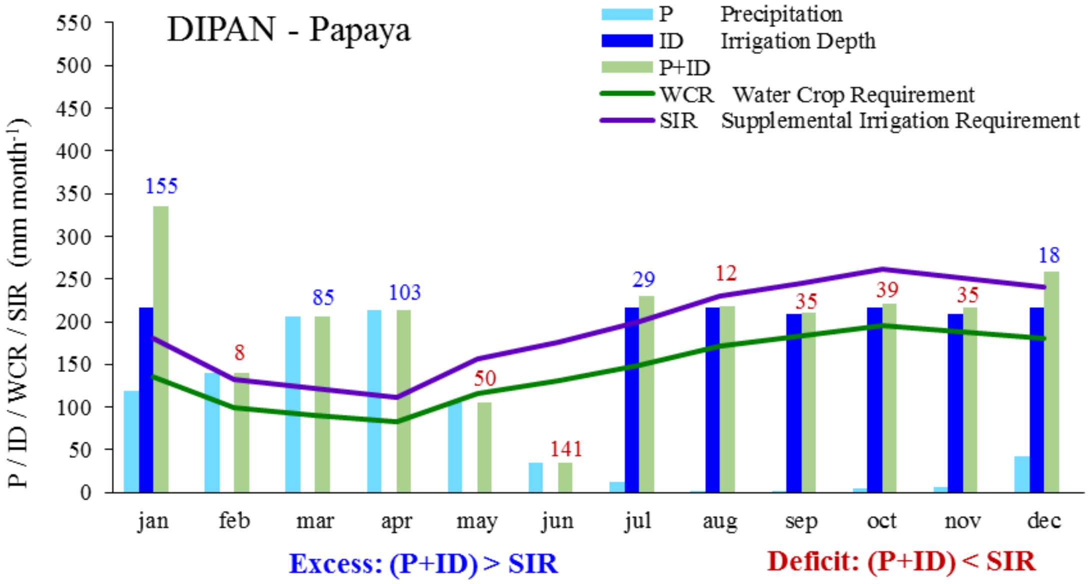
Source: Authors.

It was observed that with the lack of irrigation during the period from February to June, the precipitation was not enough to supply the water needs of the banana during the period, presenting a deficit of 61 mm, which could be provided if the surplus of 139 mm in January was stored (Figure 5).

According to Figure 6, the papaya crop did not receive sufficient irrigation depths to meet the supplemental irrigation requirement and the absence of irrigation in the period February to June caused a high water deficit for the crop of 191 mm in

May and June. Considering only the months in which irrigation was performed, improving the efficiency of irrigation application from 74.8% to 85% would provide a saving of 185.3 mm over the period, which could be set aside to make up for the deficit in June, which was the most critical month.

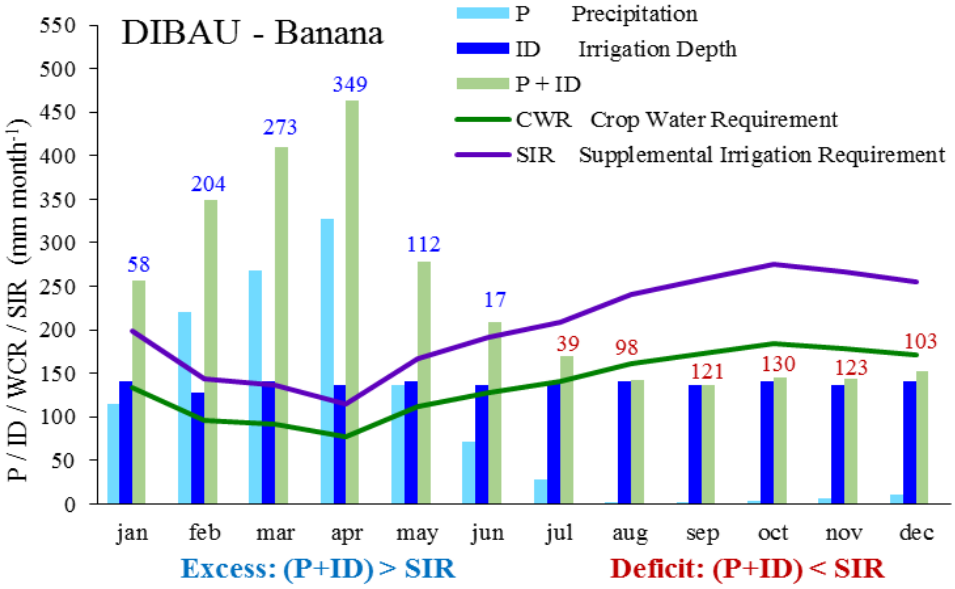
Figure 6. Irrigation demand and water balance for papaya crop produced in the Araras Norte Irrigation District (DIPAN).



Source: Authors.

The banana crop in the Baixo Acaraú Irrigation District (DIBAU) suffered a water deficit from July to December, a period of scarce precipitation, and even with irrigation, which is not being applied adequately, the irrigation depths are not sufficient to meet the crop water and irrigation requirements (Figure 7).

Figure 7. Irrigation demand and water balance of the banana crop in the Baixo Acaraú Irrigation District – DIBAU.



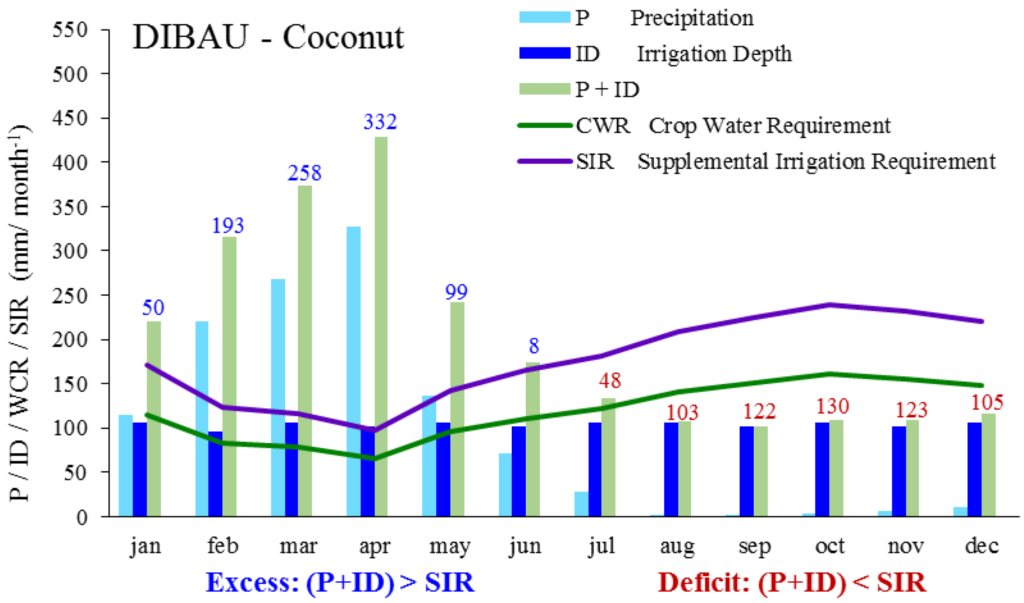
Source: Authors.

Even with applied irrigation depths insufficient to meet the crop water requirement, irrigation application efficiency is too low (67.1%) for micro-sprinkler irrigation systems (Figure 7). If irrigation application efficiency were increased to 80%, it would provide a saving of 397 mm of water applied throughout the year, which would correspond to 3970 m^3 ha^{-1}.

In the first semester the banana crop at DIBAU received a high water recharge from the precipitation, providing a very high surplus, in such a way that the irrigation depths applied were overestimated for the period.

For the coconut crop grown at DIBAU (Figure 8), it was observed that the water surplus throughout the year was due to the high precipitation recorded in the first semester.

Figure 8. Irrigation demand and water balance of the coconut crop in the Baixo Acaraú Irrigation District – DIBAU.



Source: Authors.

With the significant reduction of precipitation in the second half of the year, it was observed that the irrigation depths applied were not sufficient to meet the water requirement and coconut irrigation, demonstrating a failure in irrigation management.

4. Conclusion

The irrigation depths applied in the Araras Norte and Baixo Acaraú irrigation districts were underestimated, not meeting the supplementary irrigation requirements;

For banana and papaya crops in the Araras Norte irrigation district, performing irrigation in the first semester and applying irrigation management throughout the year could correct the water deficit;

For banana and coconut crops in the Baixo Acaraú irrigation district, it would be necessary to correct the irrigation depths in the second semester, through proper irrigation management, however, in the first semester, the precipitation was sufficient to satisfy the crop water requirement.

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