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INDICATORS AND CRITERIA TO DEFINE THE PRIORITY FOR IRRIGATION WATER USE IN THE BAIXO JAGUARIBE BASIN, BRAZIL

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ABSTRACT

The Baixo Jaguaribe basin has the smallest area of that Watershed (upper, middle and lower Jaguaribe river), but it has enormous importance in terms of water resources. The amount of water for crops irrigation is quite representative in relation to the total volume of water demanded in the entire Jaguaribe river basin. The research presents a methodology of indicators and criteria to define the priority of use of irrigation water in conditions of water scarcity. The analysis of four requirements of socioeconomic security (productive, economic, water and social) indicated a recommendation to cultivate tomato, forage palm, melon, cassava and papaya, that required the smallest water cuts for irrigation at the River Basin (less than 21%). However, crops as orange, rice, soursop, coconut, lemon, custard apple, guava, mango, banana and sugarcane must present the highest water cuts (more than 37%), mainly orange, rice, soursop, coconut, lemon and custard apple which may present values higher than 46% due to their low profitability and yield, and high water consumption.

Keywords: Productive security, water security, economic security, social security, water demand

INDICADORES E CRITÉRIOS PARA DEFINIR A PRIORIDADE NO USO DA ÁGUA DE IRRIGAÇÃO NA BACIA DO BAIXO JAGUARIBE, BRASIL

RESUMO

Embora a bacia do Baixo Jaguaribe seja a de menor área de todas as bacias do rio Jaguaribe (Alto, Médio e Baixo Jaguaribe), ela apresenta grande importância no contexto dos recursos hídricos A quantidade de água para irrigação é bastante representativa em relação ao volume total de água demandado em toda a bacia do rio Jaguaribe. A pesquisa apresenta uma metodologia de indicadores

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e de critérios para definir a prioridade de uso da água de irrigação em condições de escassez hídrica. A análise de quatro quesitos de segurança socioeconômica (seguranças produtiva, econômica, hídrica e social) indicou que é recomendável cultivar tomate, palma, melão, macaxeira e mamão, requerendo-se, neste caso, os menores cortes hídricos para irrigação na bacia (inferior a 21%). Já os cultivos de laranja, arroz, graviola, coco, limão, ata, goiaba, manga, banana e cana-de-açúcar devem sofrer os maiores corte hídricos (superior a 37%), destacando-se as culturas de laranja, arroz, graviola, coco, limão e ata com cortes hídricos sugeridos superiores a 46%, pelas baixas rentabilidades, produtividades e elevados consumos hídricos.

Palavras-chave: Segurança produtiva, segurança hídrica, segurança econômica, segurança social, demanda de água

INTRODUCTION

The growing scarcity of water and the increase in its cost led to the perception that water should be allocated and used more efficiently (LEVIDOW et al., 2014; LEIBUNDGUT; KHON, 2014). The consensus, at least among economists, is that this is best done through demand management and treating water as an economic factor (GRAFTON et al., 2018). Markets and prices can be used to help ensure usage, minimize waste, ensure efficient allocation and provide incentives for the development of water-efficient technologies, reuse and recycling (LEVIDOW et al., 2014).

Improving the management of water resources in agriculture is a priority objective worldwide, especially in semiarid territories such as the Brazilian Northeast. One of the biggest challenges in the near future will be to increase food production using less water, particularly in countries with limited water resources. In irrigated areas, the new management strategy should be based on achieving maximum gross margins, considering the sustainable use of resources, without necessarily reaching the maximum yield (CÓRCOLES et al., 2010; CÓRCOLES et al., 2016; ANGELAKIS et al., 2020).

The increase in water use may result in restrictions on its availability for use on irrigated land. In addition, the scarcity of water, typical of arid and semi-arid regions, together with a tendency to increase production costs (for example, with seeds, fertilizers and energy), establish uncertainties about the viability of irrigated agriculture, that is related to development. One of the most important characteristics of irrigated agriculture is that it must be sustainable to guarantee its viability (CÓRCOLES et al., 2012; MATEOS et al, 2018).

In recent years, the Brazilian government has made several improvements in irrigated agriculture, such as investment in new hydraulic installations and rehabilitation of older systems. In irrigation districts, the system's efficiency performance is not high, possibly not only due to hydraulic distribution facilities (MATEOS et al., 2018), but also for the inappropriate management of irrigation. It is important to analyze the performance of the irrigation system due to the high investment. One way to improve the management of scarce water resources is to increase the efficiency of water use, making investments in knowledge and human training.

Historically, water scarcity in the Ceará State was justified only by eminently climatic conditions. However, it is no longer exclusively a natural factor but also a consequence of the growing demand for multiple uses, among which irrigated agriculture, tourism, population growth and industry, dependent on large amounts of water (ADECE, 2017).

In order to optimize the management of water resources in the State of Ceará, the need became to develop tools based on decision-making processes, capable of contributing to better planning and management of water resources, with the purpose of contributing to the improvement and definition of water management strategies public management, within the State's socioeconomic interests.

The use of indicators for the assessment will enable the improvement of water resources management and its dependent public policies, considering, in addition to aspects intrinsically related to supply, economic, social and environmental aspects.

The Baixo Jaguaribe Basin is the smallest area in the three Jaguaribe Watershed (upper, middle and lower Jaguaribe River), presenting great importance in the context of water resources, as its water demand for irrigation of agricultural crops is 198,936,594 m^3, corresponding to approximately 47% of the total volume of water demanded in the Jaguaribe Basin (INESP, 2009).

The objective of this work is to develop socioeconomic indicators for the irrigated areas in the Baixo Jaguaribe Basin - CE, which, together, will allow analyzing the use of water in the irrigation of crops in this region, with a view to improving decision making in relation to management and allocation of water for irrigation in situations of water scarcity.

METHODOLOGY

The Baixo Jaguaribe Basin has a drainage area of 6,875 km^2, covering approximately 137 km, which extends from the Peixe Gordo Bridge to its outfall, in the city of Fortim (MOREIRA, 2013). That watershed has as main tributary the Palhano River, where the Santo Antônio de Russas reservoir (capacity of 24,000,000 m^3) is located, the only reservoir in this region managed by the Water Resources Management Company (COGERH). In this basin are included 9 municipalities: Aracati, Fortim, Icaupí, Itaiçaba, Jaguaruana, Limoeiro do Norte, Quixeré, Russas and Tabuleiro do Norte. The Baixo Jaguaribe Basin presents heterogeneity in the space-time distribution of rainfall, with different characteristics for the municipalities that compose it. The hot semi-arid and sub-humid climate provides average annual temperatures around 26°C to 28°C. The annual rainfall average of the River Basin is 838.0 mm (INESP, 2009).

The average annual precipitation for each municipality indicates rainfall variability for the region, from 707 mm for the municipality of Palhano to 1,435 mm for Fortim, while the average annual reference evapotranspiration varies from 1,611 mm in Fortim to 1,933 mm in Limoeiro do Norte (INESP, 2009). The rainy season is from February to May and the dry season in other months.

The municipalities with the greatest influence in the Baixo Jaguaribe basin are Limoeiro do Norte, with 7,136 ha which is irrigated with banana predominance (2,130 ha); Jaguaruana, with 4,749 ha irrigated with a predominance of sugar cane (1,800 ha) and rice (1,603 ha); Quixeré with 4,311 ha irrigated with banana predominance (2,262 ha) and Russas with 3,884 ha irrigated with banana predominance (1,183 ha) (ADECE, 2018). Socioeconomic indicators are important parameters to have a perspective of the influence of production, revenue, water consumption and job creation of irrigated crops in the Baixo Jaguaribe Basin.

To analyze the performance of irrigated crops in this watershed, socioeconomic performance indicators were used, grouped into four items, each composed of two indicators (Table 1): (a) productive security: land productivity (kg ha^{-1}), and water productivity (kg m^{-3}), (b) economic security: profitability per unit area (R\$ ha^{-1}), and profitability by quantity of applied water (R\$ m^{-3}), (c) social security: number of jobs generated per unit area (jobs ha^{-1}), and jobs per unit volume of water applied (jobs m^{-3}), and (d) water security: amount of water used for irrigation per unit area, (m^3 ha^{-1}), and time of the crop cycle. After analyzing the requirements and defining the weights applied to the indicators, the water cut was calculated, allowing to define which crops would have the highest priority in the event of water scarcity.

Table 1. Analysis requirements for the demanding sector and water allocation in conditions of water restriction and the respective indicators to which they relate

Item	**Indicator 1**	**Indicator 2**
Productivity Security	kg ha^{-1}	kg m^{-3}
Economic Security	R$ ha^{-1}	R$ m^{-3}
Social Security	Jobs ha^{-1}	Jobs m^{-3}
Water Security	m^3 ha^{-1}	Crop Cycle

The indicators were applied in the irrigated agriculture sector of the Baixo Jaguaribe Basin. Three weight levels (high, medium and low) were used in each of the indicators. In this work, the indicators of productive, economic and social security were valued as follows: (a) high weight = 1.00; (b) average weight = 0.75; and (c) low weight = 0.50. It is noteworthy that these weights were assigned arbitrarily, being possible to change them according to need and common sense, since they are input data for the model.

The issue of water security received a reverse valuation, as the indicators analyze the highest water use in the demanding sector. Thus, the high weight should receive the lowest value, that is: High weight = 0.50; average weight = 0.75, and low weight = 1.00. For each of the four items analyzed, criteria were used to apply the weight levels:

(a) Productive security : Indicator Kg ha^{-1}:

- if the productivity of the land is ≥ the maximum regional productivity of the land, the High weight = 1.00 is used;
- if the productivity of the land is between the maximum regional productivity of the land and 70% of its value, the average weight = 0.75 is used;
- if the land productivity is below 70% of the regional land productivity, the Low weight = 0.50 is used.

Indicator kg m^{-3}:

- If the productivity of the land is ≥ the maximum productivity of the regional land, the High weight = 1.00 is used;
- • If the productivity of the land is between the maximum productivity of the regional land and 70% of its value, the Average weight = 0.75 is used;
- • If the land productivity is below 70% of the regional land productivity, the Low weight = 0.50 is used.

(b) Economy Security: Indicator R$ ha^{-1}:

- • if the unitary net profit is ≥ the maximum regional unitary net profit, the weight High = 1.00 is used;
- • if the unitary net profit is between the maximum regional unitary net profit and 70% of its value, the average weight = 0.75 is used;
- • if the unitary net profit is below 70% of the maximum regional unitary net profit, the Low weight = 0.50 is used.

Indicator R$ m^{-3}:

- • if the unitary net profit is ≥ the maximum regional unitary net profit, the weight High = 1.00 is used;
- • if the unitary net revenue is between the maximum regional unitary net revenue and 70% of its value, the average weight = 0.75 is used;
- • if the unitary net profit is below 70% of the maximum regional unitary net profit, the Low weight = 0.50 is used.

(c) Social Security: Indicator job ha^{-1}:

- • if the number of employees per ha is ≥ the maximum number of employees per regional hectare, the weight High = 1.00 is used;
- if the number of employees per hectare is between the maximum number of employees per regional hectare and 70% of its value, the average weight = 0.75 is used;
- if the number of employees per hectare is below 70% of the maximum number of employees per regional hectare, the Low weight = 0.50 is used.

Indicator jobs m^{-3}:

- if the number of employees per hectare is ≥ the maximum number of employees per regional hectare, the weight High = 1.00 is used;

- if the number of employees per hectare is between the maximum number of employees per regional hectare and 70% of its value, the average weight = 0.75 is used;
- if the number of employees per hectare is below 70% of the maximum number of employees per regional hectare, the Low weight = 0.50 is used.

(d) Water Security: Indicator m³ ha^{-1}:

- if the actual water consumption is ≥ 1.3% of the ideal water consumption, the weight High (high consumption) = 0.50 is used;
- • if the actual water consumption is between the ideal water consumption and 1.3 of its value, the average weight = 0.75 is used;
- if the actual water consumption is below the ideal water consumption, the Low weight (low consumption) = 1.00 is used.

Indicator Crop Cycle:

- • if the crop is permanent, High weight (high consumption) = 0.50 is used;
- • if the crop has a long temporary cycle (over 180 days), Average weight = 0.75 is used;
- • if the crop has a short temporary cycle (below 180 days), Low weight (low consumption) = 1.00 is used.

The irrigated area, production and recipe information used in this work were obtained from the IBGE (2018), database with the exception of the forage palm, whose data used were obtained in the field. The amount of jobs generated and the actual amount of water used by activities in the River Basin were obtained from the ADECE (2018) database. The ideal water consumption by the activities was calculated by the S@I system (LIMA et al., 2015), which was the Decision Support System (SSD) chosen to perform the calculations of the indicators of each crop in the watershed.

For the calculation of crop evapotranspiration by the S@I system, data from meteorological stations belonging to the National Institute of Meteorology (INMET) and the crop coefficient published by FAO (ALLEN et al., 1998) were used. The closest weather station was adopted for each municipality, regardless of whether or not they belonged to the same River Basin. Thus, for the municipalities of Limoeiro do Norte and Tabuleiro do Norte the Morada Nova station was used. The Jaguaruana station was used for the municipalities of Jaguaruna, Itaiçaba, Acarati, Icapuí, Fortim, Russas and Quixeré.

After registering the input data in the S@I system, analyzing the socioeconomic indicators and defining the weights applied to each of the indicators, information on the suggested water cut was generated for each water demanding sector in the basin. For this, a model was used to calculate and weight the applied values by combining weights determined for each sector of analysis. The model makes a weighting of the weight valuation using the Equation (1):

$$R = \frac{(P_1 + P_2) + (E_1 + E_2) + (S_1 + S_2) + (H_1 + H_2)}{N} \quad (1)$$

Of which: P1: weight of the indicator kg ha^{-1}; P2: weight of the indicator kg m^{-3}; E1: weight of the R$ ha^{-1} indicator; E2: weight of the indicator R$ m^{-3}; S1: weight of the indicator jobs ha^{-1}; S2: weight of the jobs indicator m^{-3}; H1: weight of the indicator m³ ha^{-1}; H2: weight of the cultivation cycle indicator; N: number of indicators used (in this case, N = 8); R: weighting result with values between 0 and 1.

The result of the water cut will be as follows [Equation (2)]:

$$\%\ \text{Water Cut} = (R - 1)100 \quad (2)$$

RESULTS AND DISCUSSION

Table 2 shows the water demand for crops implanted in the municipalities of the Baixo Jaguaribe Basin. The total volume of water demanded annually by irrigated crops is 211,526,724 m^3. It is observed that the municipality of Limoeiro do Norte is the one with the highest annual water demand (64,293,198 m^3).

Then comes the municipality of Jaguaruana, with an annual demand of 46,787,151 m^3. On the other hand, the municipality of Fortim is the one that demands the lowest annual volume of water (895,008 m^3).

Table 2. Classification of municipalities in the Baixo Jaguaribe Basin regarding the annual water demand of the implanted crops (year: 2017)

City	AI (ha)	LD (mm)	LM (mm)	LA (mm)	VD (m^3)	VM (m^3)	VA (m^3)
Limoeiro do Norte	5,760	5.40	161.1	1,116.2	309,396.1	9,281,883	64,293,198
Jaguaruana	5,576	4.90	146.3	839.1	271,841.3	8,155,239	46,787,151
Quixeré	2,387	5.20	156.2	1,204.2	124,315.1	3,729,453	28,744,782
Russas	1,843	4.80	144.0	1,130.0	88,479.0	2,654,370	20,826,285
Aracati	1,707	4.70	141.4	830.9	80,442.9	2,413,287	14,183,136
Icapuí	1,498	4.50	136.5	847.9	68,138.8	2,044,164	12,701,832
Tabuleiro do Norte	456	5.50	163.7	1,242.3	24,878.6	746,358	5,664,894
Itaiçaba	612	4.70	140.3	790.9	28,613.1	858,393	4,840,308
Fortim	135	4.20	127.2	663.0	5,725.5	171,765	895,008
TOTAL	19,974	5.00	150.5	996.0	1,001,830.4	30,054,912	198,936,594

AI - irrigated area; LD - daily water demanded; LM - monthly water demanded; LA - annual water demanded; VD - daily water volume demanded; VM - monthly water volume demanded; VA - annual water volume demanded.

Table 3 shows the maximum values of the security indicators for the Baixo Jaguaribe Basin.

For productive security, it is observed that the cultivation of forage palm has the highest productivity values of the land (250,000 kg ha^{-1}). On the other hand, cocoa and pitaya crops, among all the crops found in this River Basin, showed low productivity per irrigated area (3,000 kg ha^{-1}).

Table 3. Irrigated crops in the Baixo Jaguaribe Basin and the maximum values of the analyzed criteria.

Crops	Productivity		Profitability		Water consumption	Jobs generated	
	kg ha^{-1}	kg m^{-3}	R$ ha^{-1}	R$ m^{-3}	(m^3 ha^{-1})	Jobs per ha	Jobs per 1000 m^3
Palm	250,000	45.45	40,727	1.86	5,500	0.80	0.15
Corn	29,407	2.45	7,757	0.65	12,000	0.88	0.11
Tomato	89,750	8.98	69,168	6.92	10,000	3.18	0.32
Papaya	79,785	5.32	42,001	2.80	15,000	0.55	0.04
Melon	76,518	6.96	22,253	2.55	11,000	0.72	0.07
Watermelon	73,000	6.08	3,917	0.33	12,000	0.72	0.06
Sugar cane	64,000	3.37	3,350	0.18	19,000	0.16	0.01
Coconuts	20,706	1.38	7,821	0.52	15,000	0.25	0.02
Grape	10,545	0.60	26,785	1.52	17,600	2.25	0.13
Guava	15,625	1.04	18,909	1.26	15,000	0.54	0.04
Banana	23,807	1.32	21,627	1.19	18,000	0.51	0.03
Cassava	23,000	3.19	16,293	2.26	7,200	0.56	0.08
Passion fruit	28,667	2.05	75,700	5.41	14,000	0.40	0.03
Barbados cherry	26,325	1.46	11,047	0.61	18,000	1.76	0.10

Sweet potato	10,485	1.98	12,494	2.36	10,485	1.24	0.23
Mango	13,100	0.94	15,445	1.10	14,000	0.44	0.03
Orange	14,333	0.87	7,128	0.43	16,500	0.36	0.02
Rice	13,400	0.48	5,065	0.09	28,000	0.67	0.02
Lemon	12,325	0.88	6,792	0.49	14,000	0.40	0.03
Avocado	10,200	0.54	10,404	0.55	19,000	0.81	0.04
Soursop	7,667	0.33	16,544	0.72	23,000	0.43	0.02
Custard apple	4,400	0.42	33,440	3.17	10,536	0.58	0.06
Cashew	4,217	0.60	10,772	1.54	7,000	0.16	0.02
Bean	3,000	0.40	4,157	0.48	7,500	1.07	0.14

Source: Production and employment values were obtained from IBGE (2018). except for production data for sweet potatoes. custard apple and palm that were obtained in the field. Water consumption data for crops and jobs generated were obtained from ADECE (2015). except for sweet potatoes. cassava and lime. which were obtained in the field.

In the Baixo Jaguaribe Basin, forage palm cultivation has the highest productivity values (250,000 kg ha^{-1}), much higher than other crops, such as tomatoes and papayas, which have productivity of 89,750 and 79,785 kg ha^{-1}, respectively. In addition to these crops, melon, watermelon and sugar cane stand out, all with values above 60,000 kg ha^{-1}. On the other hand, the crops of beans, cashews and custard apple were not very productive, all with productivity values below 5,000 kg ha^{-1}. Regarding water productivity, palm cultivation also had the highest value (45.45 kg m^{-3}). Tomato, melon and watermelon crops have intermediate values, greater than 6.0 kg m^{-3}. The soursop, beans, lime and rice crops had the lowest water productivity, all with values below 0.50 kg m^{-3}. Table 3 reveals low values of water productivity in the Basin, requiring irrigation management practices to increase them.

As for economic security, it is observed that the passion fruit has the best economic yield (R$ 75,700.00 ha^{-1}) and, subsequently, the tomato that has a profitability of R$ 69,168 ha^{-1}. However, tomatoes have the highest value per unit volume of water applied (R$ 6.92m^{-3}). On the other hand, sugarcane has the lowest profitability per irrigated area (R$ 3,350 ha^{-1}), while rice has the lowest economic water productivity (R$ 0.09 m^{-3}), indicating that this crop should not have preference for cultivation in the Baixo Jaguaribe Basin.

Regarding to water security in the Basin, it is observed that the rice crop has the highest water consumption per cultivated area (28,000 m^{3} ha^{-1}), followed by soursop (23,000 m^{3} ha^{-1} annually), avocado (19,000 m^{3} ha^{-1}) and sugar cane (19,000 m^{3} ha^{-1}). Some crops, such as forage palm, cashew and cassava are more economical in relation to the amount of water consumed, with 5,500, 7,000 and 7,200 m^{3} ha^{-1}, respectively.

As for social security, it is observed that the tomato crop showed the best result in relation to the amount of jobs generated by irrigated area (3.18 jobs ha^{-1}) and by the amount of water consumed (0.32 jobs per 1000 m^{3}). On the other hand, sugar cane in the last place, with the lowest amount of jobs generated (0.01 jobs per 1000 m^{3}).

Table 4 shows the irrigated areas, the daily, monthly and annual water demand for each crop implanted in each municipality in the Baixo Jaguaribe Basin. It is observed that, of the total irrigated area (19,974 ha), the banana crop occupies the largest area (4,179 ha) followed by melon (3,929 ha), watermelon (2,544 ha), rice (1,455 ha), coconut (1,105 ha), sugar cane (880 ha), papaya (835 ha) and corn (650 ha).

Table 4. Daily. monthly and annual water demand for irrigated crops grown in the municipalities of Baixo Jaguaribe (adapted from ADECE. 2018)

Municip.	Cultura	AI (ha)	DI	LD (mm)	LM (mm)	LA (mm)	VD (m^3)	VM (m^3)	VA (m^3)
Aracati	Melon	880	150	4.83	144.9	724.5	42,504.0	1,275,120	6,375,600
	Papaya	216	240	4.20	126.0	1,008.0	9,072.0	272,160	2,177,280
	Watermelon	240	140	4.83	144.9	676.2	11,592.0	347,760	1,622,880
	Banana	83	240	5.80	174.0	1.392.0	4,814.0	144,420	1,155,360
	Coconuts	21	240	4.10	123.0	984.0	810.6	24,318	885,600
	Passion fruit	45	240	4.83	144.9	1,159.2	2,173.5	65,205	521,640
	Barbados cherry	40	240	4.83	144.9	1,159.2	1,932.0	57,960	463,680
	Corn	40	180	4.35	130.5	783.0	1,740.0	52,200	313,200
	Guava	32	240	3.62	108.6	868.8	1,158.4	34,752	278,016
	Cassava	90	240	3.86	115.8	926.4	3,690.0	110,700	194,544
	Mango	12	240	4.83	144.9	1,159.2	579.6	17,388	139,104
	Bean	4	180	4.59	137.7	826.2	183.6	5,508	33,048
	Tomato	4	120	4.83	144.9	579.6	193.2	5,796	23,184
	Total	1,707		4.71	141.4	830.9	80,442.9	2,413,287	14,183,136
Fortim	Coconuts	92	120	4.10	123.0	492.0	3,772.0	113,160	452,640
	Barbados cherry	26	240	4.83	144.9	1,159.2	1,255.8	37,674	301,392
	Guava	7	240	3.62	108.6	868.8	253.4	7,602	60,816
	Cassava	3	240	3.86	115.8	926.4	115.8	3,474	27,792
	Melon	2	180	4.83	144.9	826.2	96.6	2,898	16,524
	Bean	2	150	4.59	137.7	724.5	91.8	2,754	14,490
	Watermelon	2	140	4.83	144.9	676.2	96.6	2,898	13,524
	Sweet potato	1	180	4.35	130.5	783.0	43.5	1,305	7,830
	Total	135		4.24	127.2	663.0	5,725.5	171,765	895,008
Icapuí	Melon	640	150	4.83	144.9	724.5	30,912.0	927,360	4,636,800
	Papaya	340	240	4.20	126.0	1,008.0	14,280.0	428,400	3,427,200
	Coconuts	264	240	4.10	123.0	984.0	10,824.0	324,720	2,597,760
	Watermelon	180	140	4.83	144.9	676.2	8,694.0	260,820	1,217,160
	Passion fruit	54	240	4.83	144.9	1,159.2	2,608.2	78,246	625,968
	Cassava	10	240	3.86	115.8	926.4	386.0	11,580	92,640
	Barbados cherry	4	240	4.83	144.9	1,159.2	193.2	5,796	46,368
	Guava	4	240	3.62	108.6	868.8	144.8	4,344	34,752
	Lemon	2	240	4.83	144.9	1,159.2	96.6	2,898	23,184
	Total	1,498		4.55	136.5	847.9	68,138.8	2,044,164	12,701,832
Itaiçaba	Bean	294	180	4.59	137.7	826.2	13,494.6	404,838	2,429,028
	Sugar cane	280	150	4.83	144.9	724.5	13,524.0	405,720	2,028,600
	Coconuts	27	240	4.10	123.0	984.0	1,107.0	33,210	265,680
	Soursop	6	240	4.10	123.0	984.0	246.0	7,380	59,040
	Orange	3	240	4.83	144.9	1,159.2	144.9	4,347	34,776
	Barbados cherry	2	240	4.83	144.9	1,159.2	96.6	2,898	23,184
	Total	612		4.68	140.3	790.9	28,613.1	858,393	4,840,308
Jaguaruana	Watermelon	1,920	140	4.83	144.9	676.2	92,736.0	2,782,080	12,983,040
	Melon	1,507	150	4.83	144.9	724.5	72,788.1	2,183,643	10,918,215
	Rice	740	240	5.31	159.3	1,274.4	39,294.0	1,178,820	9,430,560
	Sugar cane	600	150	4.83	144.9	724.5	28,980.0	869,400	4,347,000
	Barbados cherry	210	240	4.83	144.9	1,159.2	10,143.0	304,290	2,434,320
	Mango	203	240	4.83	144.9	1,159.2	9,804.9	294,147	2,353,176
	Orange	126	240	4.83	144.9	1,159.2	6,085.8	182,574	1,460,592
	Banana	83	240	5.80	174.0	1,392.0	4,814.0	144,420	1,155,360
	Guava	114	240	3.62	108.6	868.8	4,126.8	123,804	990,432

	Coconuts	48	240	4.10	123.0	984.0	1,968.0	59,040	472,320
	Soursop	12	240	4.10	123.0	984.0	492.0	14,760	118,080
	Bean	8	180	4.59	137.7	826.2	367.2	11,016	66,096
	Lemon	5	240	4.83	144.9	1,159.2	241.5	7,245	57,960
	Total	5,576		4.88	146.3	839.1	271,841.3	8,155,239	46,787,151
Limoeiro do Norte	Banana	1,880	240	6.20	186.0	1,488.0	116,560.0	3,496,800	27,974,400
	Bean	1,200	180	4.90	147.0	882.0	58,800.0	1,764,000	10,584,000
	Melon	900	150	5.16	154.8	774.0	46,440.0	1,393,200	6,966,000
	Rice	500	240	5.68	170.4	1,363.2	28,400.0	852,000	6,816,000
	Corn	600	180	4.65	139.5	837.0	27,900.0	837,000	5,022,000
	Lemon	167	240	5.16	154.8	1,238.4	8,617.2	258,516	2,068,128
	Coconuts	133	240	4.39	131.7	1,053.6	5,838.7	175,161	1,401,288
	Guava	112	240	3.87	116.1	928.8	4,334.4	130,032	1,040,256
	Papaya	93	240	4.49	134.7	1,077.6	4,175.7	125,271	1,002,168
	Watermelon	100	140	5.16	154.8	722.4	5,160.0	154,800	722,400
	Cassava	25	240	4.13	123.9	991.2	1,032.5	30,975	247,800
	Mango	20	240	4.13	123.9	991.2	826.0	24,780	198,240
	Barbados cherry	6	240	5.16	154.8	1,238.4	309.6	9,288	74,304
	Tomato	10	120	5.16	154.8	619.2	516.0	15,480	61,920
	Custard apple	5	240	4.39	131.7	1,053.6	219.5	6,585	52,680
	Palma	6	240	4.90	147.0	496.8	294.0	8,820	29,808
	Orange	2	240	5.16	154.8	1,238.4	103.2	3,096	24,768
	Cashew	1	180	3.91	117.3	703.8	39.1	1,173	7,038
	Total	5,760		5.37	161.1	1,116.2	309,396.1	9,281,883	64,293,198
Quixeré	Banana	1,300	240	5.80	174.0	1,392.0	75,400.0	2,262,000	18,096,000
	Coconuts	310	240	4.10	123.0	984.0	12,710.0	381,300	3,050,400
	Rice	155	240	5.31	159.3	1,274.4	8,230.5	246,915	1,975,320
	Mango	142	240	4.83	144.9	1,159.2	6,858.6	205,758	1,646,064
	Papaya	150	240	4.20	126.0	1,008.0	6,300.0	189,000	1,512,000
	Bean	115	180	4.59	137.7	826.2	5,278.5	158,355	950,130
	Watermelon	100	140	4.83	144.9	676.2	4,830.0	144,900	676,200
	Guava	60	150	3.62	108.6	543.0	2,172.0	65,160	325,800
	Barbados Cherry	11	240	4.83	144.9	1,159.2	531.3	15,939	127,512
	Lemon	10	240	4.83	144.9	1,159.2	483.0	14,490	115,920
	Soursop	10	240	4.10	123.0	984.0	410.0	12,300	98,400
	Corn	10	180	4.35	130.5	783.0	435.0	13,050	78,300
	Tomato	12	120	4.83	144.9	579.6	579.6	17,388	69,552
	Orange	2	240	4.83	144.9	1,159.2	96.6	2,898	23,184
	Total	2,387		5.21	156.2	1,204.2	124,315.1	3,729,453	28,744,782
Russas	Banana	833	240	5.80	174.0	1,392.0	48,314.0	1,449,420	11,595,360
	Guava	469	240	3.62	108.6	868.8	16,977.8	509,334	4,074,672
	Coconuts	210	240	4.10	123.0	984.0	8,610.0	258,300	2,066,400
	Lemon	40	240	4.83	144.9	1,159.2	1,932.0	57,960	463,680
	Orange	36	240	4.83	144.9	1,159.2	1,738.8	52,164	417,312
	Barbados cherry	34	240	4.83	144.9	1,159.2	1,642.2	49,266	394,128
	Papaya	36	240	4.20	126.0	1,008.0	1,512.0	45,360	362,880
	Cashew	45	150	3.91	117.3	586.5	1,759.5	52,785	263,925
	Rice	20	240	5.31	159.3	1,274.4	1,062.0	31,860	254,880
	Cassava	20	240	3.83	114.9	919.2	766.0	22,980	183,840
	Sweet potato	33	120	4.35	130.5	522.0	1,435.5	43,065	172,260
	Avocado	15	240	4.10	123.0	984.0	615.0	18,450	147,600
	Grape	11	240	4.10	123.0	984.0	451.0	13,530	108,240
	Bean	8	180	4.59	137.7	826.2	367.2	11,016	66,096
	Mango	5	240	4.83	144.9	1,159.2	241.5	7,245	57,960
	Passion fruit	5	240	4.83	144.9	1,159.2	241.5	7,245	57,960

	Palm	10	240	4.59	137.7	496.8	459.0	13,770	49,680
	Tomato	8	120	4.83	144.9	579.6	386.4	11,592	46,368
	Soursop	3	240	4.10	123.0	984.0	123.0	3,690	29,520
	Watermelon	2	140	4.83	144.9	676.2	96.6	2,898	13,524
	Total	1,843		4.80	144.0	1,130.0	88,479.0	2,654,370	20,826,285
Tabuleiro do Norte	Banana	180	240	6.20	186.0	1,488.0	11,160.0	334,800	2,678,400
	Lemon	90	240	5.17	155.1	1,240.8	4,653.0	139,590	1,116,720
	Rice	40	240	5.68	170.4	1,363.2	2,272.0	68,160	545,280
	Papaya	30	240	4.49	134.7	1,077.6	1,347.0	40,410	323,280
	Corn	33	180	4.65	139.5	837.0	1,534.5	46,035	276,210
	Watermelon	30	140	5.17	155.1	723.8	1,551.0	46,530	217,140
	Cassava	20	240	4.13	123.9	991.2	826.0	24,780	198,240
	Bean	20	180	4.90	147.0	882.0	980.0	29,400	176,400
	Coconuts	10	240	4.39	131.7	1,053.6	439.0	13,170	105,360
	Guava	3	240	3.87	116.1	928.8	116.1	3,483	27,864
	Total	456		5.46	163.7	1,242.30	24,878.60	746,358	5,664,894

DI - number of irrigation days.

In the municipalities of Acarati and Icapuí, the crop of melon is the largest demand for water, with an important difference between the other crops. In the municipality of Jaguaruana, watermelon is the crop that demands the most water, followed by melon. In the municipality of Fortim, with the smallest irrigated area among the municipalities, the annual water demand is 895,008 m^3, showing the coconut crop with the highest annual water demand (452,640 m^3). Itaiçaba has six irrigated crops, consuming an annual volume of 4,840,308 m^3. Among them, the crops of beans and sugar cane are those that consume the most water and the crops of orange and barbados cherry are those that consume the least. In Limoeiro do Norte, bananas and beans have the highest annual water demands. In Quixeré, with fourteen irrigated crops, banana and coconut crops are the biggest water users. The municipality of Russas has a wide variety of irrigated crops (22), with banana and guava being the most used water. In Tabuleiro do Norte the greatest need for water occurs for banana cultivation.

Figura 1 shows the results for suggested water cuts for each of the irrigated crops implanted in the Baixo Jaguaribe Basin, in percentage. The priority for water use will be for the crop has the less water cut. Table 5 shows the suggested water cuts, for each of the irrigated crops implanted in the Baixo Jaguaribe Basin, in volume of water used and the area corresponding to the percentage of water cut.

Table 5. Suggested water cut for each irrigated crop implanted in the Baixo Jaguaribe Basin

Crop	Water Cut			Crop	Water Cut		
	%	Volume m^3	Área ha		%	Volume m^3	Área ha
Orange	50.00	1,394,250	84.5	Sweet potato	34.00	121,206	11.6
Rice	46.00	38,060,400	1,359.3	Cashew	34.00	109,480	15.6
Soursop	46.00	327,980	14.3	Bean	31.00	3,620,025	482.7
Coconuts	46.00	8,183,400	545.6	Grape	28.00	54.208	3.1
Lemon	46.00	2,022,160	144.4	Passion fruit	28.00	407,680	29.1
Custard apple	46.00	24,232	2.3	Corn	28.00	2,294,880	191.2
Guava	43.00	5,179,350	345.3	Watermelon	28.00	8,648,640	720.7
Mango	43.00	2,299,640	164.3	Papaya	21.00	2,724,750	181.6
Banana	40.00	31,680,000	1,760.0	Cassava	15.00	106,920	14.8
Sugar cane	37.00	6,186,400	325.6	Melon	12.00	2,009,040	182.6
Avocado	34.00	96,900	5.1	Palm	9.00	32,670	5.9
Barbados cherry	34.00	2,037,960	113.2	Tomato	6.00	20,400	2.0

Total water cut volume = 117,642,571 m^3
Total reduction of corresponding area = 7,004.8 ha

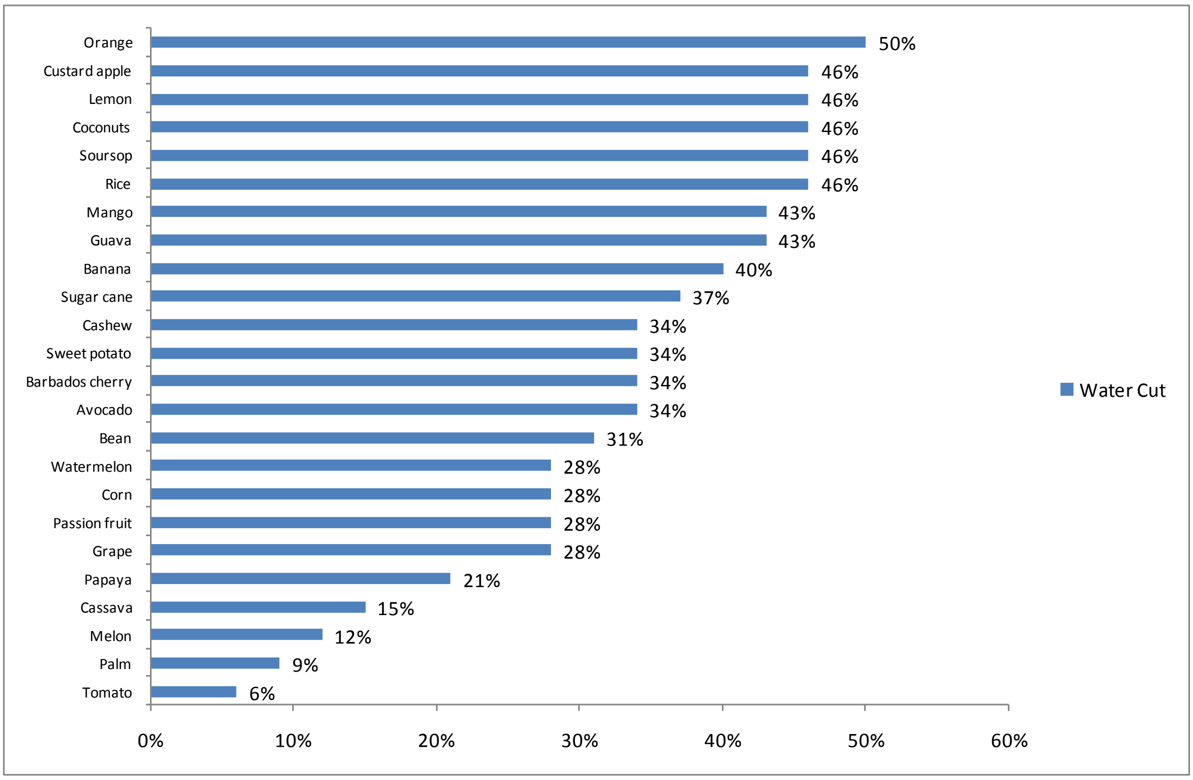

Figura 1. Water cut for each irrigated crop in the Baixo Jaguaribe Basin

In the Baixo Jaguaribe Basin, a 50% water cut is suggested for the orange crop (1,394,250 m^3) or an area reduction of 84.5 ha. Following are rice, soursop, coconut, lemon and custard apple crops with 46% suggested water cut.

Among the crops that would have priority for cultivation in case of water scarcity, are tomatoes, palm and melon, suggesting a water cut of 6, 9 and 12%, respectively. In total, the suggested cuts would result in savings of 117,642,571 m^3 per year for the Basin, which would correspond to a reduction of 7,843 ha irrigated, if irrigation management is carried out with current consumption.

The results obtained indicate water scarcity and the need to improve the performance of irrigated agriculture in this region. Some options available to improve the sustainability of irrigated agriculture in this River Basin, at the level of the irrigated plot, are: (a) agronomic factors: adopt a cultivation system to improve the use of precipitation or reduce water evaporation; improve soil fertility; improve the soil structure and increase the capacity to store water and nutrients through the incorporation of organic matter; use advanced cultivation strategies that maximize the cultivated area during periods of lower water demand or when rain may be more likely to occur (ALI, et al. 2005; WALLACE and BATCHELOR, 1997); (b) engineering factors: improving the uniformity of irrigation water distribution; use conservation, maintenance and repair programs for irrigation systems and hydraulic structures to reduce the risk of water loss; design wastewater treatment and reuse systems on the farm; modernize and optimize irrigation systems (ALVAREZ et al., 2004; PLAYÁN and MATEOS, 2006); (c) irrigation management factors: promoting irrigation with small to moderate deficits to enable the extraction of deeper water from the soil; perform irrigations at low wind speed times to reduce losses due to evaporation and drift, or use windbreaks; minimize salinity in the root zone of crops (ALI et al., 2008; VAZIFEDOUST et al. 2008); (d) institutional factors: adopt a water pricing system; promote incentives for the efficient use of water and penalties for inefficient use; promote user education and training to learn modern irrigation techniques; encourage technical assistance and the dissemination of knowledge (PERRY, et al. 2009); (e) economic factors: reallocating water from crops of lower economic value to crops of greater economic value; when land availability is restricted and water is relatively unrestricted, use irrigation to maximize income per unit area; when water is restricted and the land is relatively unrestricted, irrigate to maximize income per unit volume of water (FRIZZONE, 2004).

CONCLUSIONS

The research of socioeconomic indicators for irrigated crops, implanted in the Baixo Jaguaribe Basin, has provided the following conclusions for sustainable agriculture in the region:

(a) For better productive security, with regard to physical land productivity (kg ha^{-1}) and physical water productivity (kg m^{-3}), the cultivation of forage palm, tomato, papaya, melon and watermelon is suggested.

(b) For economic security, analyzing the economic productivity of the land (R\$ ha^{-1}), the cultivation of passion fruit, tomato, papaya, palm and lime is suggested; and for better economic productivity of water (R\$ m^{-3}), tomato, passion fruit, lime, papaya and melon are indicated.

(c) To contribute to the water security of the River Basin, the cultivation of palm, cashew, cassava, beans and tomatoes is suggested, reducing the cultivated areas with rice, soursop, avocado, sugar cane, banana and Barbados cherry. As for the crop cycle, preference should be given to those with a short or medium cycle, avoiding permanent crops to reduce the risk of major losses in the event of water scarcity.

(d) The crops that promote the greatest number of jobs per ha are tomatoes, grapes, Barbados cherry, sweet potatoes and beans; the greatest number of jobs per m^3 of water applied was achieved with the cultivation of tomatoes, sweet potatoes, palm, beans and grapes.

(e) The weighting of the four socio-economic security issues analyzed indicated that, in case of water scarcity, it is recommended to cultivate tomatoes, palm, melon, cassava and papaya, requiring, in this case, the smallest water cuts for irrigation in the basin (less than 21%). The orange, rice, soursop, coconut, lemon, guava, mango, banana and sugar cane cultivations are expected to suffer the largest water cuts (over 37%), especially orange, rice, soursop, coconut, lemon and custard apple with suggested water cuts above 46%, due to low profitability, productivity and high water consumption.

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