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Profitability of using irrigation in forage cactus-sorghum intercropping for farmers in semi-arid environment[1]

Rentabilidade do uso da irrigação no consórcio palma-sorgo para agricultores em ambiente semiárido

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HIGHLIGHTS:

Forage cactus-sorghum intercropping provides economic advantage for production in the semi-arid regions of Northeast Brazil.
The forage cactus-sorghum intercropping system promotes a high yield of fresh matter.
The highest net revenue values can be achieved by implementing the forage cactus-sorghum system.

ABSTRACT: Irrigation plays a fundamental role in advancing agricultural frontiers and increasing crop productivity, especially in semi-arid environments, because they exhibit high spatiotemporal rainfall variation. This practice is suggested even for adapted crops, such as forage cactus (*Opuntia* sp.), sorghum (*Sorghum bicolor*), and single or intercropping systems. In this study, aimed to evaluate the profitability of using irrigation in a single and intercropping forage cactus-sorghum system in a semi-arid region. The experimental design was in randomized blocks in a 5 × 3 factorial arrangement: five drip irrigation depths (0, 25, 50, 75, and 100% of the reference evapotranspiration – ET_0) and three cropping systems (single forage cactus, single sorghum, and intercropping forage cactus-sorghum), with four replicates. The 0% ET_0 treatment corresponded to rainfed conditions at a depth of 355 mm. A cycle of forage cactus and two sorghum cultivars (plant and regrowth) was conducted between November 2014 and November 2015. It was verified that the highest costs for implantation of the crop systems in irrigated conditions are due to the acquisition of irrigation and input systems, representing 85.3% of the effective operational cost. The single sorghum and forage cactus-sorghum systems provided the highest fresh matter productivity (62,013.05 and 60,075.36 kg ha^{-1}, respectively). Based on economic indicators, the adoption of irrigation depths (25, 50, 75, and 100% ET_0) promoted profits for the systems (single and intercropping) from the second year of implementation.

Key words: economic indicators, net revenue, operational cost, *Opuntia* sp., *Sorghum bicolor*

RESUMO: O uso da irrigação desempenha papel fundamental no avanço das fronteiras agrícolas e no aumento da produtividade nas áreas de cultivo, principalmente em ambientes semiáridos que apresentam alta variação espaço-temporal de chuvas. Essa prática é sugerida até mesmo para cultivos adaptados como palma forrageira (*Opuntia* sp.) e sorgo (*Sorghum bicolor*). Assim, objetivou-se avaliar a rentabilidade do uso da irrigação no sistema solteiro e sistema consorciado palma-sorgo no semiárido. O delineamento experimental foi em blocos casualizados em esquema fatorial 5 × 3: cinco lâminas de irrigação por gotejamento (0, 25, 50, 75 e 100% da evapotranspiração de referência - ET_0) e três sistemas de cultivo (palma forrageira solteira, sorgo solteiro e consórcio palma-sorgo), com quatro repetições. O tratamento 0% ET_0 correspondeu à condição de sequeiro com uma lâmina de 355 mm. Foi conduzido um ciclo de palma e dois de sorgo (planta e rebrota) compreendidos de novembro 2014 a novembro de 2015. Verificou-se que os maiores custos para implantação dos sistemas de cultivo em condições irrigadas se devem à aquisição do sistema de irrigação e insumos, representando 85,3% do custo operacional efetivo. O sistema sorgo solteiro e o sistema palma forrageira-sorgo proporcionaram as maiores produtividades de matéria fresca (62.013,05 e 60.075,36 kg ha^{-1}), respectivamente. Com base em indicadores econômicos, a adoção de lâminas de irrigação (25, 50, 75 e 100% ET_0) promoveu lucros para os sistemas (solteiro e consorciado) a partir do segundo ano de implantação.

Palavras-chave: indicadores econômicos, renda líquida, custo operacional, *Opuntia* sp., *Sorghum bicolor*

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Introduction

Rainfed agriculture in arid and semi-arid regions is difficult to establish because of the spatiotemporal variations in rainfall in these areas (Félix et al., 2020; Mbava et al., 2020). Therefore, irrigation plays an important role in reducing losses and maximizing crop productivity by improving the spatiotemporal distribution of water in arid and semi-arid regions (Ferraz et al., 2019; Kankarla et al., 2019; Morais et al., 2022).

Another interesting practice in these regions is intercropping, which reduces the risk of soil erosion and incidences of pests and diseases and improves the physical properties of soil, the stability of the crop, production per unit area, and monetary return to the producer (Wang et al., 2020; Xu et al., 2020; Jardim et al., 2020a).

The forage cactus-sorghum configuration is interesting in terms of animal diet. The forage cactus (*Nopalea* and *Opuntia*) is rich in water and carbohydrates; however, it has low levels of fibers and proteins (Jardim et al., 2020b). Sorghum (*Sorghum* spp.) is rich in fibers that have nutritional characteristics similar to corn; however, it has low water demand and high temperature tolerance (Diniz et al., 2017; Jardim et al., 2021a).

Although the use of irrigation and intercropping of forage cactus-sorghum is advantageous in increasing production and nutrition, the implementation of these practices depends upon agro-economic indicators, which allow the producers to make decisions based on the revenue obtained (Dutra et al., 2015; Sun et al., 2018; Alves et al., 2022).

Considering the previous knowledge regarding the benefits of irrigation and forage cactus intercropped systems, it is hypothesized that the forage cactus-sorghum intercropped system under complementary irrigation will result in better economic gains and yields. Therefore, this study aimed to evaluate the profitability of using irrigation in a single forage cactus system, single sorghum system, and intercropping forage cactus-sorghum system in a semi-arid region.

Material and Methods

The present study was conducted from November 2014 to November 2015 in the municipality of Serra Talhada (7º 59' S, 38º 15' W, altitude 431 m) in the state of Pernambuco, Brazil, located in the Sertão zone of the state with a territorial area of 2,979.9 km^2. It has a semi-arid climate according to the Köppen climate classification BSh, with a mean air temperature of 28.8 ºC, high atmospheric demand of 1,800 mm, and rainfall of 642 mm per year (Pereira et al., 2015) (Figure 1).

The observed mean maximum and minimum temperatures were 32.9 and 21.0 °C, respectively, with a relative air humidity of 58.5%, total rainfall of 355 mm, and reference evapotranspiration – ET_0 of 1,500 mm during the experimental period. The soil of the experimental area was classified as Ultisol, with total porosity of 40.4%; bulk density of 1.5 kg dm^{-3}; and contained 692.1 g kg^{-1} of sand, 249.2 g kg^{-1} of silt, and 58.8 g kg^{-1} of clay, respectively, at depths of 0.00–0.20 m.

It was used the forage cactus clone Orelha de Elefante Mexicana (*O. stricta* (Haw.)) and sorghum cv. SF-15 (*S. bicolor* (L.) Moench) distributed in a randomized block design in a 5 × 3 factorial scheme, with four replicates: five irrigation water depths (0, 25, 50, 75, and 100% of ET_0) and three cropping systems (forage cactus in a single system, forage sorghum in a single system, and forage cactus-sorghum in an intercropping system). The total applied water depths (irrigation plus rainfall) were 355, 563, 725, 867, and 1,012 mm per year, respectively. Rainfall corresponding to the rainfed treatment (0% of ET_0) during the experimental period was 355 mm per year.

The drip irrigation system was used (1.35 L h^{-1} flow rate at 100 kPa of working pressure and 93% distribution

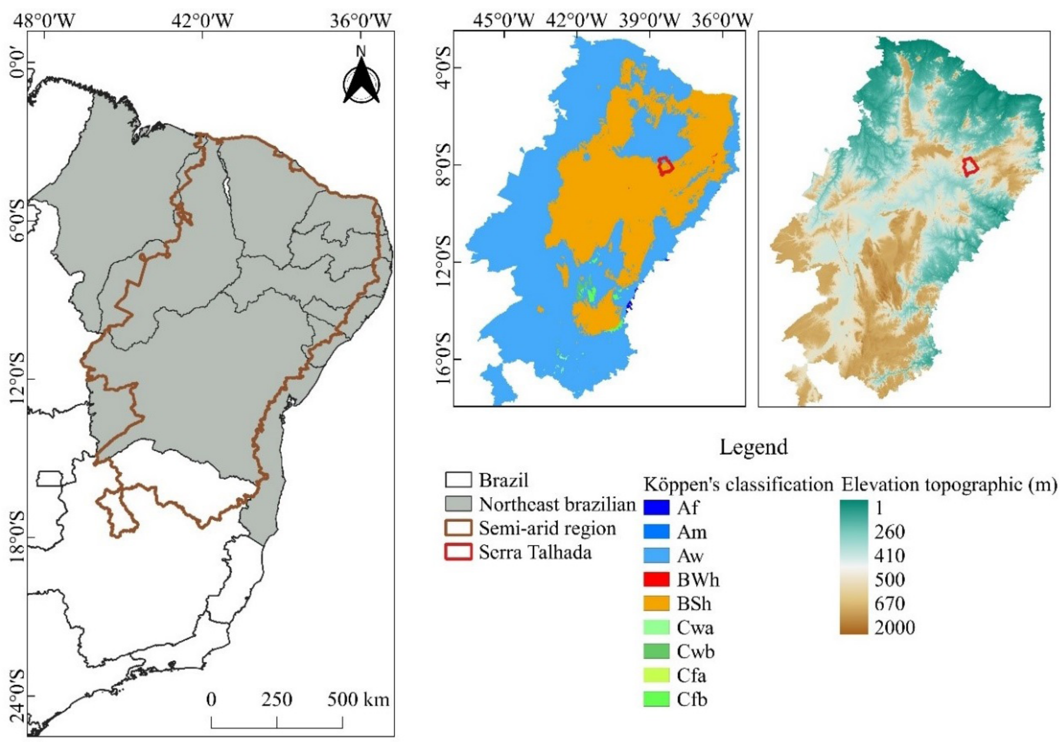


Figure 1. Location of the study area in the municipality of Serra Talhada, PE, Brazil

uniformity coefficient), with drip tapes positioned next to the rows of cropping in single systems and 0.4 m spacing. In the intercropping system, an irrigation drip tape was placed between the rows of forage cactus and sorghum to benefit the two crops from the supplied water. The irrigation depth was estimated using the Penman-Monteith method standardized by FAO Bulletin 56 (Allen et al., 1998), based on daily meteorological data obtained from the automatic station of the National Institute of Meteorology, located 1.5 km from the experimental area. The irrigation events were carried out three days a week using saline water coming from Dam Saco (electrical conductivity between 1.6 and 2.5 dS m^{-1}).

The mechanization activities for the preparation of the area took place by plowing, harrowing, and furrowing the soil in a level curve for later planting of forage cactus cladodes. The forage cactus with a spacing of 1.6 × 0.4 m was planted in a single system in 2011, totaling 15,625 plants ha^{-1}. However, in the present study, no fourth productive cycle was initiated in November 2014 and maintained during the harvest of the previous cycle or basal cladode. Forage sorghum cv. SF-15 single system was planted in January 2015 in four rows of 6.0 m, with 1.6 m space between rows, resulting in a population density of 170,000 plants ha^{-1} (approximately 28 plants m^{-1}). The forage cactus-sorghum intercropping system was made up of 92% forage sorghum (170,000 plants ha^{-1}) and 8% forage cactus (15,625 plants ha^{-1}) plants, with forage cactus planted in a spacing of 1.6 × 0.4 m and interspersed with forage sorghum rows having 0.2 m distance. During the experimental period, two mineral fertilizations were performed with NPK using the 14-00-18 + 16S formulation (73.5 kg N ha^{-1}, 94.5 kg K_2O ha^{-1}, and 84 kg S ha^{-1}, respectively). Weed control was performed manually.

The harvest of the first sorghum cycle was carried out 147 days after sowing (May 2015). The second harvesting (regrowth assessment) was performed 102 days after the first cut (September 2015), when the dry mass content was between 28 and 30%. In each plot, 10 plants were selected, cut at 0.10 m above the soil surface, and weighed to obtain fresh matter. The total yield of sorghum resulted from the extrapolation of the fresh matter and final density of the plants. During the harvest of forage cactus, the basal cladode was maintained, and the fresh matter yield of 22 plants for each experimental plot in the study area was obtained by measuring their weight using an electronic balance. This process was followed by the extrapolation of productivity (e.g., the fresh weight of the plots and final density of the plants). Furthermore, the total number of cladodes in each forage cactus plant was determined during harvesting.

The production costs of single and intercropping systems were calculated based on the methodology used by Dutra et al. (2015), according to which total operating cost (TOC) comprises the expenditure of resources, such as mechanized operations, manuals, and equipment. The parameters that influence the TOC are effective operating cost (EOC) and costs and administrative burden (CAB) described as follows: the EOC corresponds to the variable costs or direct expenses with financial disbursement for the activities that prepare the soil until harvest, electricity, and depreciation of the irrigation system. Their values were raised from the mean prices practiced in the region by different institutions and enterprises during 2015. The CAB represents fixed costs or indirect expenses related to interests, social charges, administration fees, depreciation of equipment, and electricity costs.

The profitability of forage cactus and sorghum in the single and intercropping systems under irrigation conditions were calculated by estimating the costs of implementing and maintaining these systems. The methodology suggested by Lima et al. (2018) was used to calculate the equipment depreciation costs. All assessments of the technical coefficients of costs and depreciation were quoted in Brazilian real currency (R$, also known as BRL), and the exchange rate was 1 US$ equals 3.28 BRL at the time of data compilation using Eq. 1.

$$DC = \frac{CAV - 0.2 \times CAV}{UL} \tag{1}$$

where:

DC - depreciation of the system component (R$);

CAV - component acquisition value (R$);

0.2 × CAV - scrap or residue value (R$) (value referring to 20% or 0.2 of the purchase value of each component); and,

UL - useful life span (years).

The scrap value was calculated by considering 20% of the component's purchase value. Useful life values of the equipment were obtained according to the methodology described by Lima et al. (2018). The cost of energy power (CEP) was calculated using Eq. 2; and the value for kWh used was R$ 0.42.

$$CEP = V_{kWh} \times T \times \left(\frac{736 \times Pot}{1000 \times \eta} \right) \tag{2}$$

where:

CEP - cost of energy power (R$);

V_{kWh} - kWh value (R$);

T - total operation time of irrigation system (h), variable for each planting type system;

Pot - engine-pump set power (horse power - hp); and,

η - pump-engine set yield (decimal).

Monetary advantage (MA) is a way of calculating the economic advantage of the intercropping system; the higher this index, the greater the profitability of the cropping system (Baxevanos et al., 2017; Jardim et al., 2021b). It was calculated according to the expression given below (Eq. 3).

$$MA = GR \times \left(\frac{LER - 1}{LER} \right) \tag{3}$$

where:

MA - Monetary advantage;

GR - gross revenue of the forage cactus-sorghum system (i.e., the production value of the intercropping system); and,

LER - land equivalent ratio (i.e., the relative land area required for single crops to produce the same yields as intercropping).

To evaluate the MA of the forage cactus-sorghum intercropping system, the costs of services and inputs performed during the experiment were considered. Expenses were based on the sale price of R$ 100.00 per ton of fresh matter for both crops (CONAB, 2020). Profitability was obtained through the indicators of GR, net revenue (NR), and other factors, such as gross margin (GM), which indicates the leftover budget to remunerate fixed costs in the short term; the benefit-cost ratio (BCR); and the profitability index (PI), calculated according to Eqs. 4, 5, 6, 7, and 8, respectively.

$$GR = \left(Y_{crop} \times Y_{value}\right) \tag{4}$$

where:

GR - gross revenue obtained from the sale of cactus as forage (R$);

Y_{crop} - crop yield (t ha^{-1}); and,

Y_{value} - the value of crop yield (R$ per tons), considering the price set to R$ 100.00 per tons.

$$NR = \left(GR - TPC\right) \tag{5}$$

$$GM = \left(GR - EOC\right) \tag{6}$$

$$BCR = \left(\frac{GR}{TPC}\right) \tag{7}$$

$$PI = \left(\frac{NR}{GR}\right) \times 100 \tag{8}$$

where:

NR - net revenue (R$ ha^{-1} per year);

GM - gross margin (R$ ha^{-1} per year);

GR - gross revenue (R$ ha^{-1} per year);

EOC - effective operating cost (R$ ha^{-1} per year);

BCR - benefit-cost ratio;

TPC - total production cost (R$ ha^{-1}); and,

PI - profitability index (%); the index is compelling since it represents the rate of revenue available for the activity after deducting all operating costs.

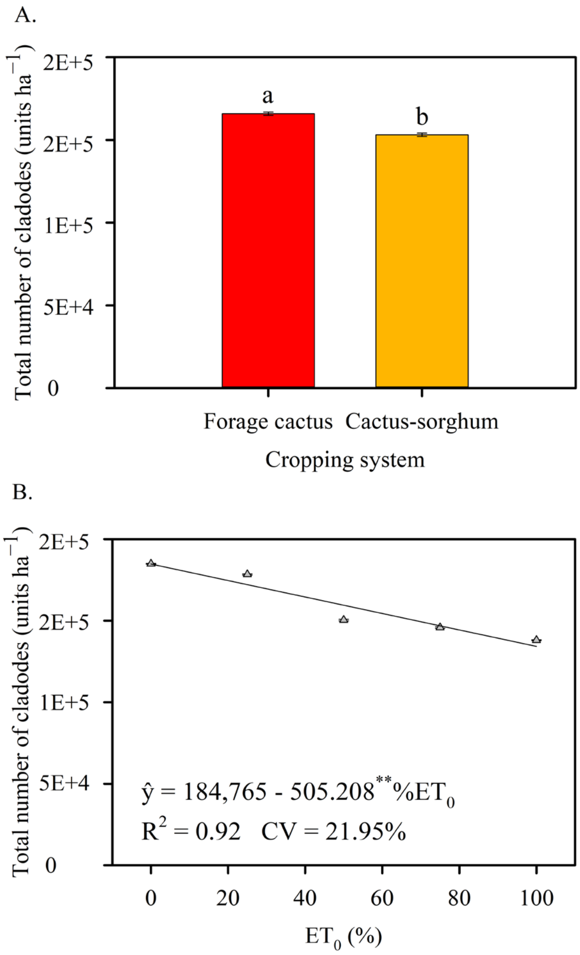
The data were compiled in a spreadsheet, and the costs were calculated to obtain the total and net revenue from the cropping systems. In this study, an economic profitability analysis was conducted on the difference between the total revenue (i.e., production multiplied by product price) and total cost.

Data on the number of forage cactus cladodes and sorghum yield in both cropping systems were subjected to tests of normality (Shapiro-Wilk test), homogeneity, and analysis of variance ($p \leq 0.05$); when presenting significant values, their means were compared by the Tukey test ($p \leq 0.05$). The effect of water depths on the number of forage cactus cladodes and sorghum yield were analyzed using regression analysis ($p \leq 0.05$). All data analyses were performed using R software version 4.0.1.

Results and Discussion

The yield of sorghum was not significantly affected by the water depths and cropping systems ($p > 0.05$) and had a mean value of 11.32 t ha^{-1}. The interaction between irrigation depth and cropping system did not affect the total number of cladodes (TNC) of the forage cactus ($p > 0.05$). A significant effect ($p \leq 0.05$) on isolated factors was observed (irrigation depths and cropping systems) for the TNC of the forage cactus clone Orelha de Elefante Mexicana (Figure 2). For the cropping systems (Figure 2A), a mean TNC of 153,125 units ha^{-1} was observed in the forage cactus-sorghum intercropping system, which was 7.69% lower than that of the forage cactus single system (165,885 units ha^{-1}).

In Figure 2B, a decrease of 505,208 units ha^{-1} in TNC was observed with each increment of the irrigation depth. The mean TNC values estimated by the regression equation were 184,765 and 134,244 for irrigation depths of 0 and 100% ET_0, respectively, with a reduction of 27.34%. Lima et al. (2018) studied the intercropping of forage cactus with sorghum under different irrigation depths and obtained a mean of 205,000 units ha^{-1} (15,625 plants ha^{-1}), with an increase of 22.2% due



** - Significant at $p \leq 0.01$ by the F test; Means followed by different letters indicate significant difference ($p \leq 0.05$) by the Tukey's test; CV - Coefficient of variation; The vertical bars - Standard error of the mean

Figure 2. The total number of cladodes (TNC) of forage cactus clone Orelha de Elefante Mexicana in the single (forage cactus) and intercropping (forage cactus-sorghum) system (A), and the TNC in the single system as a function of irrigation depth (B)

to a larger water depth applied. However, with a rainfall of 977 mm per year (0% ET_0), the water depth was 175.21% higher than that observed in this study for the same fraction of ET_0.

Table 1 describes the production costs of forage cactus and sorghum in single and intercropping systems under different water regimes. It expresses the fixed and variable costs of resources used in production in R$ ha^{-1}. Among the irrigated treatments, there was a notable increase in the TOC because of the increase in the water depths applied, owing to higher expenses associated with electricity.

The factors that contributed the most to the increase in total cost of irrigated systems were buying irrigation equipment and inputs (6,317.40 and 2,062.50 R$ ha^{-1}, respectively). Similar results were obtained by Dantas et al. (2017) in the Potiguar semi-arid region for the production of irrigated and high-density forage cactus (50,000 plants ha^{-1}), with higher expenses of 5,700.00 and 15,097.80 R$ ha^{-1} due to the irrigation systems (i.e., equipment, pump, connections, and installations) and inputs (i.e., cladodes, fertilizers, and chemicals), respectively.

There was minimal variation in the TOC for the implementation of the single forage cactus, single sorghum, and intercropping forage cactus-sorghum systems. However, an increase in the TOC was observed between the various applied irrigation depths because of the higher cost of electricity, which was 26% higher at 100% ET_0 than at lower applied irrigation depths (25% ET_0). For single and intercropping forage cactus, the highest TOC was found in the 1,012 mm irrigation depths (100% ET_0), with 10,125.33 and 10,255.33 R$ ha^{-1}, respectively, whereas, in this system, energy costs were higher (410.04 R$ ha^{-1}). Lima et al. (2018) studied the same configuration with the sorghum cultivar 2502 and found that the increase in TOC occurred with the largest water depth applied.

On comparing the single and intercropping systems, the highest TOC was observed in the intercropping system owing to the large number of inputs required (Table 1). Lima et al. (2018) cited this same behavior in the TOC due to a greater need for inputs; however, a higher yield was reported in their system. Dutra et al. (2015) also observed an increase in the TOC while evaluating castor bean and peanut intercropping, with the highest being 1,452.11 US$ ha^{-1}.

For the irrigated single sorghum system, variations were found in the TOC ranging from 8,106.50 to 8,407.83 R$ ha^{-1}.

Table 1. Description of production costs of forage cactus (Orelha de Elefante Mexicana) and sorghum (cv. SF-15) in single cropping and intercropping systems under different irrigation depths, based on fractions of the reference evapotranspiration (ET_0) in the municipality of Serra Talhada, PE, Brazil

Items of the description of costs	Fractions of the ET_0				
	0%	25%	50%	75%	100%
			Single forage cactus system		
A - Effective operating cost (R$ ha^{-1})					
Irrigation system	†	6,317.40	6,317.40	6,317.40	6,317.40
Implementation of crop	550.00	550.00	550.00	550.00	550.00
Cultural practices	280.00	280.00	280.00	280.00	280.00
Inputs	2,062.50	2,062.50	2,062.50	2,062.50	2,062.50
Subtotal (A)	2,892.50	9,209.90	9,209.90	9,209.90	9,209.90
B - Costs and administrative burden (R$ ha^{-1})	†				
Electricity	550.00	108.71	196.40	300.40	410.04
Depreciation of components	280.00	505.39	505.39	505.39	505.39
Subtotal (B)	2,062.50	614.10	701.79	805.79	915.43
A+B - Total operating cost (R$ ha^{-1})	2,892.50	9,824.00	9,911.69	10,015.69	10,125.33
			Single sorghum system		
A - Effective operating cost (R$ ha^{-1})					
Irrigation system	†	6,317.40	6,317.40	6,317.40	6,317.40
Implementation of crop	505.00	345.00	345.00	345.00	345.00
Cultural practices	280.00	280.00	280.00	280.00	280.00
Inputs	550.00	550.00	550.00	550.00	550.00
Subtotal (A)	†	7,492.40	7,492.40	7,492.40	7,492.40
B - Costs and administrative burden (R$ ha^{-1})					
Electricity	†	108.71	196.40	300.40	410.04
Depreciation of components	†	505.39	505.39	505.39	505.39
Subtotal (B)	†	614.1	701.79	805.79	915.43
A+B - Total operating cost (R$ ha^{-1})	1,335.00	8,106.50	8,194.19	8,298.19	8,407.83
			Intercropping forage cactus-sorghum system		
A - Effective operating cost (R$ ha^{-1})					
Irrigation system	†	6,317.40	6,317.40	6,317.40	6,317.40
Implementation of crop	630.00	630.00	630.00	630.00	630.00
Cultural practices	280.00	280.00	280.00	280.00	280.00
Inputs	2,112.50	2,112.5	2,112.5	2,112.5	2,112.5
Subtotal (A)	†	9,339.90	9,339.90	9,339.90	9,339.90
B - Costs and administrative burden (R$ ha^{-1})					
Electricity	†	108.71	196.40	300.40	410.04
Depreciation of components	†	505.39	505.39	505.39	505.39
Subtotal (B)	†	614.1	701.79	805.79	915.43
A+B - Total operating cost (R$ ha^{-1})	3,022.50	9,954.00	10,041.69	10,145.69	10,255.33

† - Does not apply

This value was lower compared to the irrigated single forage cactus because of the lower cost of its "seeds." The acquisition costs for cladodes were 1,562.50 R$ ha^{-1}, whereas the costs for sorghum seeds were 50.00 R$ ha^{-1} for experimental conditions. Compared to that reported in Lima et al. (2018), the implantation of sorghum culture had a cost of 265.00 R$ ha^{-1}. The lowest TOC for both single and intercropping systems was observed when irrigation was not used (Table 1), with values ranging from 1,335.00 to 3,022.50 R$ ha^{-1}. This is because of the absence of expenses related to the irrigation system, water, and energy costs, which are responsible for ensuring a 20% reduction in TOC, according to Dutra et al. (2015).

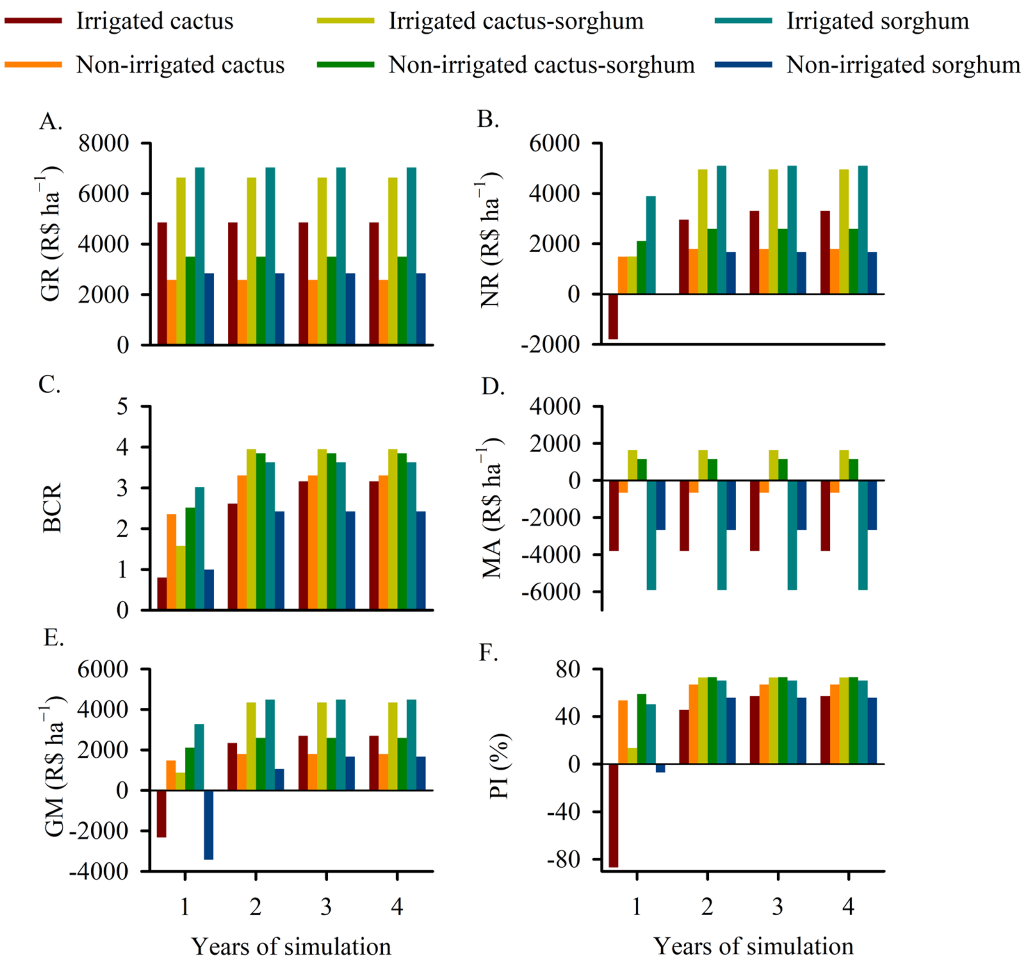
Figure 3 illustrates various monetary advantage indicators, i.e., gross revenue (GR), net revenue (NR), benefit-cost ratio (BCR), monetary advantage (MA), gross margin (GM), and profitability index (PI) of forage cactus and sorghum in intercropping and single systems under different irrigated conditions.

By simulated four productive years of these crops and discerned that in the first year, the systems with irrigated single forage cactus and 0% ET_0 single sorghum reached negative values of NR, GM, and PI (Figures 3B, E, and F, respectively), demonstrating no economic return because the revenue did not exceed the outlay. These results corroborate with that of Lima et al. (2018), who also found that NI did not exceed the costs of implanting and maintaining the system when the yield of the forage cactus was sold as forage; however, it was profitable when the product was sold as "seeds."

The GR (Figure 3A) depends directly on the yields and prices paid for the product, reaching higher profitability in intercropping systems. This is due to its high yield values, and the factor that it is economically advantageous provides high profit (Kheroar & Patra, 2014). The BCR (Figure 3C) for the first productive year of the single irrigated forage cactus was < 1.0, whereas it was > 3.0 for the intercropping system, indicating that each R$ 1.00 invested had a return of more than R$ 3.00.

The MA index (Figure 3D) is directly proportional to crop yield. Negative values of MA were observed for single cropping forage cactus and sorghum due to the lower LER of the single system. Intercropping systems have a higher LER, and thus, lead to better crop yield and positive values of MA (Baxevanos et al., 2017).

In the second productive year, all systems exhibited profitability. By overcoming the expenses imposed, the highest values of net revenue were observed in the forage cactus-sorghum system, indicating a greater economic return compared to that of the single systems; additionally, diversifying food, favoring the seasonality of forage production for animals and providing better profitability to rural producers on the farm.



GR - Gross revenue; NR - Net revenue; BCR - Benefit-cost ratio; MA - Monetary advantage; GM - Gross margin; PI - Profitability index

Figure 3. The profitability of forage cactus (*O. stricta* (Haw.)) and sorghum (*S. bicolor* (L.) Moench) under irrigated and rainfed conditions in single and intercropping systems in the municipality of Serra Talhada, PE, Brazil

Conclusions

1. Irrigation did not increase the fresh matter productivity of the forage cactus in the first year after the implementation of the drip system. The irrigation depths (25, 50, 75, and 100% ET_0) and the intercropping forage cactus-sorghum system promoted profits from the second year of implementation.

2. The sorghum single and intercropping systems had the best product performance when irrigated with at least 50% ET_0. The mean values of effective operating cost contributed the most to the formation of total costs (91.9%), of which 83.60% resulted from spending on the irrigation system (suction, discharge, and motor pump).

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