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Agro-bioeconomic feasibility of immature cowpea and beet cultivar combinations in a semi-arid environment

Viabilidade agrobioeconômica de combinações de cultivares de feijão caupi imaturo e de beterraba em ambiente semiárido

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ABSTRACT - The objective of this work was to evaluate the agro-bioeconomic feasibility of immature cowpea and beet cultivar combinations in intercropping systems in a semi-arid environment. Experiments were carried out in two cropping years using a randomized block design with four replicates. The treatments consisted of four cowpea cultivars (‘BRS Tumucumaque,’ ‘BRS Cauamé,’ ‘BRS Guariba,’ and ‘BRS Itaim’) and two beet cultivars (‘Early Wonder’ and ‘Fortuna’). In each block of the experiments, plots in monocropping of the cultivars were sown as additional treatments to obtain the following agronomic and competition indexes and economic indicators: land equivalent ratio (LER), area time equivalent ratio (ATER), land efficiency (LUE), beet equivalent production (BEP), competitive ratio (CR), crop aggressivity (A), gross income (GI), net income (NI), rate of return (RR), and corrected monetary advantage (CMA). The highest agro-bioeconomic efficiency of the tested intercropping systems was achieved in the combination of cowpea cultivar BRS Guariba and beet cultivar Fortuna. Beet behaved as the dominant crop, and cowpea as the dominated crop in all evaluated intercropping systems. The indexes and indicators demonstrated the complementarity and sustainability of the combination of cowpea cultivar BRS Guariba with beet cultivar Fortuna.

Keywords: *Beta vulgaris*. *Vigna unguiculata*. Plant competition indexes. Intercropping. Sustainability.

RESUMO - O objetivo deste trabalho foi avaliar a viabilidade agrobioeconômica de combinações de cultivares de feijão-caupi imaturo e de beterraba em sistemas consorciados em ambiente semiárido. Os experimentos foram conduzidos em dois anos agrícolas, em delineamento de blocos casualizados com quatro repetições. Os tratamentos consistiram da combinação de quatro cultivares de feijão-caupi (‘BRS Tumucumaque,’ ‘BRS Cauamé,’ ‘BRS Guariba’ e ‘BRS Itaim’) e duas cultivares de beterraba (‘Early Wonder’ e ‘Fortuna’). Em cada bloco dos experimentos, parcelas em monocultivo das cultivares foram semeadas como tratamentos adicionais para obtenção dos seguintes índices agronômicos e de competição e indicadores econômicos: razão equivalente de terra (RET), razão equivalente de área no tempo (REAT), eficiência de uso da terra (EUT), produção equivalente de beterraba (PEB), razão competitiva (RC), indice de superação das culturas (ISC), renda bruta (RB), renda líquida (RL), taxa de retorno (TR) e vantagem monetária corrigida (VMC). A mais alta eficiência agrobioeconômica dos sistemas consorciados testados foi alcançada na combinação da cultivar de feijão-caupi BRS Guariba com a cultivar de beterraba Fortuna. A beterraba se comportou como a cultura dominante e o feijão-caupi como a cultura dominada em todos os consórcios avaliados. Os índices e indicadores determinados demonstraram a complementaridade e sustentabilidade da combinação da cultivar de feijão-caupi BRS Guariba com a cultivar de beterraba Fortuna.

Palavras-chave: *Beta vulgaris*. *Vigna unguiculata*. Índices de competição de plantas. Consorciação de culturas. Sustentabilidade.

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INTRODUCTION

One of the biggest challenges in intercropping production systems is the choice of crops and the ‘ideal’ combination of cultivars to be used (COSTA et al., 2017). The proper selection of cultivars of companion crops is the key to success in intercropping systems and hastens crop growth and yield in a complementary manner. One of the questions raised by farmers is whether beet and cowpea are crops that are successful when grown in association and whether their cultivars, when combined, offer agro-bioeconomic benefits to the cropping system.

Beet and cowpea are two companion crops of economic and nutritional value that complement each other in an intercropping system because they have different plant architectures and root systems (CHAVES et al., 2020; DESRAVINES et al., 2022). Thus, an intercropping system between these crops has been recognized as a potentially beneficial system of agricultural production, as it increases the total yield of crops per unit of land per unit of time, increases the diversity of products, reduces the economic risks of the producer, and helps to efficiently and judiciously use the land, labor, and environmental resources of rural land.

In the semi-arid region of northeastern Brazil, beet and cowpea have been cultivated as monocrops (SILVA et al., 2013; ALMEIDA et al., 2019). Commercial cultivars of these crops have been developed by companies for exploitation in this production system. Although the intercropping system is widely used in the region, studies on the combination of these materials in intercropping are incipient. Therefore, it is important to search for information about which combination of cultivars of these crops can offer a high yield and agro-bioeconomic efficiency to the system, as well as products with high quality and high nutritional value.

Azevedo et al. (2021), studying the combination of radish and cowpea cultivars in intercropping systems in the semi-arid region of northeastern Brazil, emphasized that to obtain an advantage in a combination of crops, the cultivars involved must present differences between their needs in relation to the available resources, whether in quality, quantity, or time demand. Thus, the careful choice of cultivars, as well as their association or establishment times, is of paramount importance in providing maximum use of the advantages of the intercropping system.

In the intercropping system, the crops and cultivars involved are not necessarily sown at the same time but are mostly grown simultaneously, thus promoting an interaction. Therefore, it is crucial to select cultures that are companions and cultivars that exert some complementarity. This is possible when the species have different ecological niches, thus maximizing the use of light and the absorption of water and nutrients (AZEVEDO et al., 2021). Tuberous beet and legume cowpea can meet this principle and thus provide agro-bioeconomic advantages when intercropped.

To provide greater scientific subsidies to immature cowpea and beet intercropping, this work aimed to evaluate the agro-bioeconomic viability of combinations of cowpea and sugar beet cultivars in intercropping systems in a semi-arid environment.

MATERIAL AND METHODS

Experiments were conducted in two different research areas from August to October 2016 and October to December 2017, at the “Rafael Fernandes” Experimental Farm of the Universidade Federal Rural do Semi-Árido (UFERSA), located in the Lagoinha district (5°03' S, 37°25' W, 18 m altitude), Mossoró, RN, Brazil.

The region is considered semi-arid, and the climate is ‘BShw,’ according to the Köppen classification, that is, dry and very hot, with two well-defined climatic seasons: a drought season that usually runs from June to January and a rainy season from February to May (ALVARES et al., 2014). The data for the maximum and minimum temperatures and relative humidity during the experimental periods are shown in Figure 1.

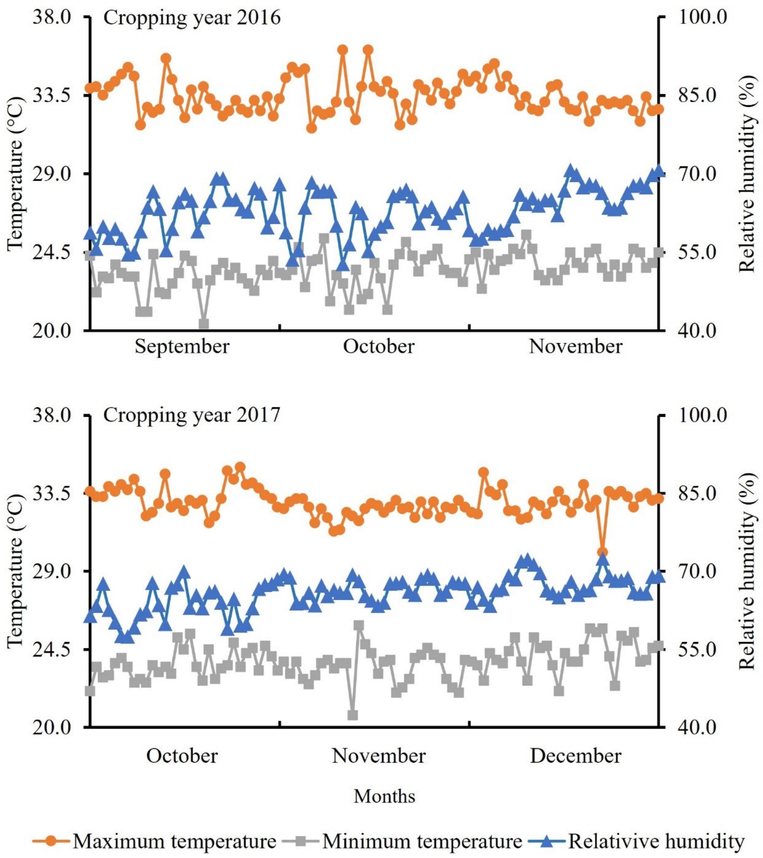

Figure 1. Temperatures and relative humidity of the cropping years of 2016 and 2017 provided by INMET (National Institute of Meteorology).

The soil in the experimental area was classified as typical dystrophic Red Argisol (SANTOS et al., 2018). Soil presented the following chemical properties in the first cropping year: pH (water) = 8.2; N = 0.51 g kg^{-1}; OM = 3.64 g kg^{-1}; P = 10.30 mg dm^{-3}; K^+ = 57.20 mg dm^{-3}; Ca^{+2} = 0.60 $cmol_c$ dm^{-3}; Mg^{+2} = 0.58 $cmol_c$ dm^{-3}; Na^+ = 11.60 mg dm^{-3}; and EC = 1.77 ds m^{-1}. In the second cropping year, these properties were as follows: pH = 6.60; N = 0.42 g kg^{-1}; OM = 3.65 g $kg^{-1;}$ P = 34.2 mg dm^{-3}; K^+ = 69.2 mg dm^{-3}; Ca^{+2} = 3.10 cmolc dm^{-3}; Mg^{+2} = 0.80 $cmol_c$ dm^{-3}; Na^+ = 19.0 mg dm^{-3}; and EC = 1.05 ds m^{-1}.

The experimental design was randomized complete blocks, with eight treatments and four replicates. The treatments consisted of four cowpea cultivars (‘BRS Tumucumaque,’ ‘BRS Cauamé,’ ‘BRS Guariba,’ and ‘BRS Itaim’) combined with two beet cultivars (‘Early Wonder’ and ‘Fortuna’). These materials are recommended for monocropping in semi-arid conditions in northeast Brazil (LIMA et al., 2013; SILVA, 2017). The first three cowpea cultivars presented semi-erect plants and indeterminate growth habits, and the last cultivar was erect and had a determinate growth habit. These cowpea cultivars have a production cycle between 65 and 70 days. The Early Wonder beet cultivar was tall, with elongated leaves and a cycle between 60 and 65 days, while the Fortuna cultivar was medium sized, with elongated leaves and a cycle between 65 and 75 days. In each block, a plot of each cultivar in monocropping was sown as an additional treatment to obtain agro-bioeconomic indexes.

The monocropping plots contained six rows. The total area of each cowpea experimental plot was 3.60 m^2, with a harvest area of 2.00 m^2. For beet, the total area was 1.44 m^2, with a harvest area of 0.80 m^2. Cowpea was sown in the 0.50 m spacing between rows with 10 plants per linear meter, with a population density of 200,000 plants per hectare (COSTA et al., 2017), while beet was sown in a spacing of 0.20 m × 0.10 m, with a density of 500,000 plants per hectare (SOUSA et al., 2018).

The intercropping system was formed by combining cowpea cultivars with beet cultivars. Each experimental plot was composed of a strip of four rows of cowpea alternating with a strip of four rows of beet flanked by two rows of cowpea on one side and two rows of beet on the other side, thus constituting the lateral borders of the plots of each treatment. The total area of the experimental plot was 3.60 m^2, with a useful area of 2.00 m^2, with 50% of the area cultivated with cowpea and 50% with beet. The spacing adopted for cowpea and beet was 0.25 m between cultivation lines and between plants, which were 0.10 m and 0.04 m, respectively, totaling 40 and 100 cowpea and beet plants in the harvest area (Figure 2). The same planting population densities of the crops in the monocropping system were used in the intercropping system.

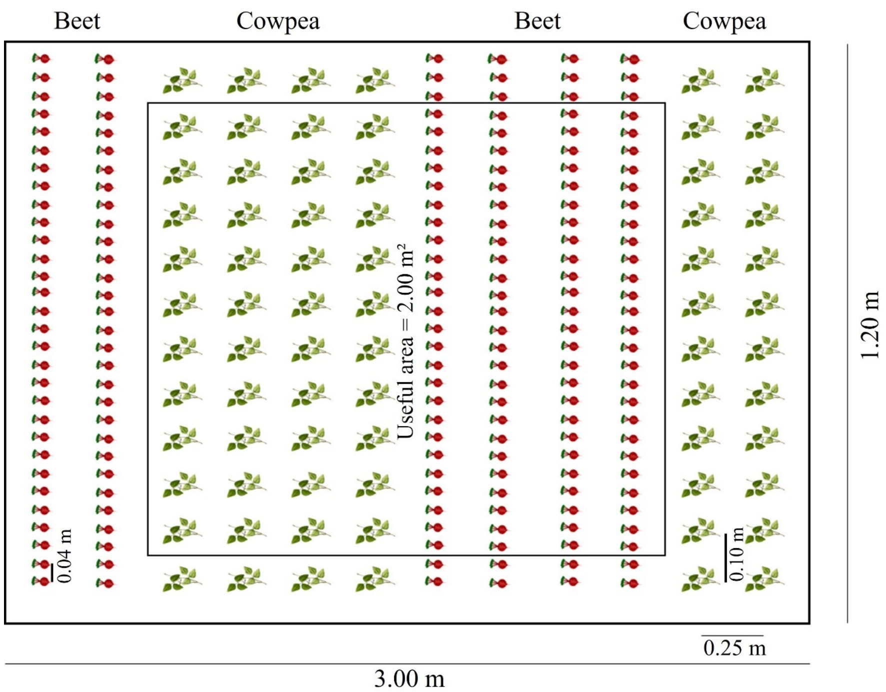

Figure 2. Detail of a plot of the beet–cowpea intercropping system at the same beet and cowpea population densities as in the monocropping system.

The green manure *Calotropis procera* was used to fertilize the experiments. Chemical analyses of this material showed the following contents: N = 18.4 g kg^{-1}; P = 3.14 g kg^{-1}; K = 4.5 g kg^{-1}; Ca = 16.30 g kg^{-1}; and Mg = 13.35 g kg^{-1}. Fertilization of the crops was carried out in the 0–20 cm layer of the soil 20 days before planting, in the amount of 46.84 t ha^{-1} of the green manure recommended by the research.

The two crops were sown simultaneously on August 23, 2016, and October 10, 2017. The replanting and thinning of the cowpea and beet crops were carried out at 7 and 10 days and at 11 and 14 days after sowing in 2016 and 2017, respectively. Hand tools and a micro-sprinkler system were used for weeding and irrigation, respectively. The growth cycle from sowing to harvesting for green cowpea grains ranged from 54 to 69 days and that of beet 71 days in both years.

The productivities of immature cowpea and beet were recorded, and from them, the indices of agronomic–biological efficiency, economic efficiency, and competition of the cowpea and beet cultivar combinations were determined.

The indexes of the agronomic–biological efficiency parameters evaluated were as follows:

a) The land equivalent ratio (LER) was calculated using the following expression: $LER = LER_c + LER_b = (Y_{cb} / Y_{cm}) + (Y_{bc} / Y_{bm})$. LER_c and LER_b expressions represent the land equivalent ratio for cowpea and the land equivalent ratio for beet, respectively, whereas Y_{cb} and Y_{cm} represent the productivity of cowpea in intercropping with beet and in monocropping, respectively. Y_{bc} and Y_{bm} indicate the productivity of beet in intercropping with cowpea and in monocropping, respectively. An LER of more than 1 indicates a productivity advantage; when it is equal to 1, there is neither an increase nor a decrease in productivity, and a value of less than 1 indicates a productivity loss (CECÍLIO FILHO et al., 2013).

b) The area time equivalent ratio (ATER) was calculated by the following expression (DINIZ et al., 2017): $ATER = [(LER_c \times T_c) + (LER_b \times T_b)] / T$, where LER_c and LER_b represent the land equivalent ratios for cowpea and beet, T_c and T_b represent the time spent on the cowpea and beet crops, and T represents the time spent on the entire system. If ATER > 1, then there is a productive advantage in the intercropping system. If ATER = 1, there is no productive advantage, and if ATER < 1, there is a productive disadvantage in this system.

c) Land use efficiency (LUE) is calculated using the following expression: LUE% = [(LER + ATER) / 2] × 100. If LUE > 100%, intercropping has an advantage over monocropping (GENDY; NOSIR; NAWAR, 2017). If LUE = 100%, there is no productive advantage, and if LUE < 100%, intercropping is at a disadvantage compared to monocropping.

d) Beet equivalent production (BEP) was determined by the following equation: $BEP = Y_b + r\,Y_c$ (BATISTA et al., 2016), where Y_b and Y_c are the productivities of beet (main crop) and cowpea (secondary crop) in intercropping and r is the ratio between average cowpea and beet prices. The prices paid to producers in the western region of the Rio Grande do Norte state for green cowpea grains in 2016 and 2017 were R$ 7.50 and R$ 6.50 per kilo, respectively, and for beet roots, the prices were R$ 2.50 and R$ 2.00 per kilo. Thus, the ratio of average prices in these two years was 3.11.

The economic indexes evaluated in the intercropping system were gross income (GI), determined by multiplying the value of production obtained per hectare by the price paid to the producer at the market level in the region in October 2016 and December 2017. The net income (NI) was calculated using the following expression: NI = GI – TC, where TC represents the total costs of the treatment (FERREIRA et al., 2022). The rate of return (RR) was obtained by the ratio between gross income and total costs (RR = GI / TC). The corrected monetary advantage was determined by the following expression: CMA = NI × (LER − 1 / LER) (OLIVEIRA et al., 2015).

The competition indexes evaluated in the intercropping systems of the cultivar combinations were: competitive ratio (CR) and crop aggressivity indexes (A). CR was obtained using the following formula: $CR = [(LER_b / LER_c) \times (Z_{cb} / Z_{bc})] + [(LER_c / LER_b) \times (Z_{bc} / Z_{cb})]$ (CECÍLIO FILHO et al., 2013), where LER_b and LER_c were obtained from the LER expression, Z_{bc} being the proportion of beet sown in intercropping with cowpea, and Z_{cb} the proportion of cowpea sown in intercropping with beet. CR is an index that assesses the competition between different intercropped systems and provides a better measure of the competitive capacity of component crops. The system with the highest CR makes better use of environmental resources.

Aggressivity (A) of beet on cowpea (A_{bc}) and the aggressivity of cowpea on beet (A_{cb}) were determined by the following expressions: $A_{bc} = (Y_{bc} / Y_{bm} \times Z_{bc}) - (Y_{cb} / Y_{cm} \times Z_{cb})$ and $A_{cb} = (Y_{cb} / Y_{cm} \times Z_{cb}) - (Y_{bc} / Y_{bm} \times Z_{bc})$. When A is positive, the crop with a positive sign is dominant, and the crop with a negative sign is dominated.

The index data were submitted to joint analysis of variance over the cropping years through the SISVAR program (FERREIRA, 2011). The Bartlett test was used to verify the homogeneity of the variances. The mean differences of the cultivar combinations were separated and tested using the Hsu test at the 5% significance level (HSU, 1981).

If an effect of the larger treatment is the best, even if the best treatment is unknown, the parameters of preliminary interest can be defined as: $\max_{j=1,\dots,k} \mu_j - \mu_i, i = 1,\dots,k,$ (1), where the difference between the effect of the best treatment true and each one of the treatment's k-effects (ESTATCAMP, 2014). However, in most cases, it is advantageous to compare each treatment with the best of the other treatments. Suppose that the greatest effect of treatment implies better treatment. Then, the parameters contain all the information for the parameters given by Expression (1). Naturally, if the smallest effect of the treatment implies the best treatment, then by symmetry the preliminary parameters of interest are: $\mu_i - \min_{j \neq i} \mu_j, i = 1,\dots,k$.

If the best treatment is the highest average between factor levels, according to Hsu, a set of intervals with a confidence level of (1 − a) × 100%, simultaneous for the difference between the mean of the i-th factor level and the maximum between the averages of the other levels of the factor, must be obtained. The limits of these intervals were calculated using the following equations:

$$D_i^- = -\left[\bar{y}_{i.} - \max_j(\bar{y}_{j.}) - d_\alpha(k, N-k)\sqrt{2\left(\frac{QME}{n}\right)}\right]^- \text{ Lower limit}$$

$$D_i^+ = \left[\bar{y}_{i.} - \max_j(\bar{y}_{j.}) + d_\alpha(k, N-k)\sqrt{2\left(\frac{QME}{n}\right)}\right]^+ \text{ Upperlimit}$$

,

where $d_\alpha(k, N-k)$ is a tabulated value (HSU, 1981) that depends on the number of levels (k) and the number of degrees of freedom of errors (N - k)) and n_i is the number of replicates of level i (for unbalanced data). For balanced data, all n_i are equal. If the interval (D_i^-; D_i^+) assumes only positive values, we consider that the i-th level of the factor is the best. Thus, $[D_i^-] = \min\{0, D_i^-\} = \begin{cases} D_i^- \text{ if } x < 0 \\ 0 \text{ otherwise} \end{cases}$ and $[D_i^+] = \max\{0, D_i^+\} = \begin{cases} D_i^- \text{ if } x > 0 \\ 0 \text{ otherwise.} \end{cases}$

Joint analysis was accomplished for each index or indicator over the cultivation years 2016 and 2017. The best combination of cultivars, in a set of simultaneous confidence intervals for paired comparisons between the best mean (of higher value) and one of the other treatment means, was identified through the Software Action (ESTATCAMP, 2014).

RESULTS AND DISCUSSION

There was no significant interaction between cowpea and beet cultivar combinations and cropping years in the agronomic–biological efficiency indexes. However, significant differences between the cropping years and between the cultivars' combinations of cultures were recorded (Table 1).

Table 1. F test and mean values for land equivalent ratio (LER), area time equivalent ratio (ATER), land use efficiency (LUE), and beet equivalent production (BEP) from the combinations of cowpea and beet cultivars[(1)].

Sources of Variation	DF	LER	ATER	LUE (%)	BEP
Blocks (Cropping years)	6	2.85*	3.65**	3.27**	2.38*
Cropping years (Y)	1	38.89**	22.14**	37.36**	1.40NS
Cultivar combinations (C)	7	3.34**	4.40**	3.78**	2.39*
Y x C	7	2.04NS	2.08NS	2.02NS	1.14NS
Cropping years					
2016	-	1.31b †	0.88b	175.35b	14.35b
2017	-	1.60a	1.03a	211.57a	15.04a
CV (%)	-	12.76	12.92	12.25	15.97

[(1)] Means followed by different lowercase letters in the column differ from each other by the F test at a 5% probability. ** = P < 0.01; * = P < 0.05; NS = P > 0.05.

The mean values of LER and LUE in all combinations of cowpea and beet cultivars were greater than 1 and 100%, respectively, indicating the advantage of intercropping over monocropping. In terms of ATER, this advantage was observed only in the combinations of the cultivars BRS Guariba with Fortuna and BRS Itaim with Early Wonder, where values greater than the unit were recorded.

The highest mean values of the LER, ATER, LUE, and BEP indices were recorded in the combination of cultivar BRS Guariba and cultivar Fortuna. The values of LER and ATER indicate a production advantage of 68 and 12% with the use of this combination; that is, 68 and 12% more area would be required in the monocropping of these cultivars to provide the same production obtained with the intercropping system (Table 2). In contrast, intercropping BRS Guariba and Fortuna showed efficiency with a 124% LUE index.

These results are highly relevant for the semi-arid region as they show agronomic advantages or benefits in combining cowpea and sugar beet cultivars. This means that the appearance of highly productive genotypes improved for single production systems can be successfully used in intercropping by exploiting environmental resources efficiently and producing highly productive and superior systems compared to cultivars exploited in monocultures. Research with combinations of tuberous cultivars, such as carrot and radish with cowpea, in the semi-arid region of the northeast has shown satisfactory results (COSTA et al., 2017; AZEVEDO et al., 2021). This indicates that the combination of beet cultivars with cowpea can be characterized by cultural complementarity and consequently produce viable intercropped systems in a semi-arid environment.

Table 2. Mean values ($\overline{Y}$), differences between the means of the i-th combination and the maximum between the means of the other combinations (D), and the simultaneous confidence intervals (SCI) of these differences for the land equivalent ratio (LER), area time equivalent ratio (ATER), land use efficiency (LUE), and beet equivalent production (BEP) from the combinations of cowpea and beet cultivars.

Cultivar combinations		LER				ATER			
		$\overline{Y}$	D	SCI		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	1.46	−0.22	−0.48	0.04	0.99	−0.12	−0.31	0.06
BRS Tumucumaque	Fortuna	1.54	−0.15	−0.41	0.11	1.00	−0.12	−0.30	0.07
BRS Cauamé	Early Wonder	1.31	−0.37	−0.63	0.00	0.87	−0.25	−0.43	0.00
BRS Cauamé	Fortuna	1.35	−0.33	−0.59	0.00	0.87	−0.25	−0.43	0.00
BRS Guariba	Early Wonder	1.42	−0.26	−0.52	0.00	0.87	−0.24	−0.43	0.00
BRS Guariba	Fortuna	1.68	0.15	−0.11	0.41	1.12	0.08	−0.11	0.26
BRS Itaim	Early Wonder	1.50	−0.19	−0.45	0.07	1.04	−0.08	−0.26	0.11
BRS Itaim	Fortuna	1.37	−0.31	−0.57	0.00	0.92	−0.20	−0.38	0.00
		LUE				BEP			
		$\overline{Y}$	D	SCI		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	196.02	−28.27	−62.45	5.90	14.71	−2.01	−4.94	0.92
BRS Tumucumaque	Fortuna	203.35	−20.95	−55.13	13.22	15.09	−1.63	−4.56	1.30
BRS Cauamé	Early Wonder	174.54	−49.75	−83.93	0.00	13.63	−3.09	−6.02	0.00
BRS Cauamé	Fortuna	178.54	−45.76	−79.93	0.00	14.21	−2.51	−5.44	0.42
BRS Guariba	Early Wonder	186.02	−38.28	−72.45	0.00	14.47	−2.25	−5.18	0.68
BRS Guariba	Fortuna	224.30	20.95	−13.22	55.13	16.72	1.63	−1.30	4.56
BRS Itaim	Early Wonder	201.58	−22.72	−56.89	11.46	14.84	−1.88	−4.81	1.05
BRS Itaim	Fortuna	183.33	−40.97	−75.15	0.00	13.90	−2.82	−5.75	0.12

Analyzing the cropping years on these agronomic indexes, it was observed that 2017 provided the highest values for these indexes. This is due to the better climatic conditions this year in relation to 2016, providing crops with better growth and development and consequently higher yields (Figure 1).

This result may also be related to the morphological characteristics of the cultivars in combination, among which the size of the plants that, in the case of the Guariba cowpea cultivar, had a semi-erect plant and an indeterminate growth habit, and that were taller than beet plants. Both crops presented cylindrical trifoliate broad leaves for cowpea and elongated leaves for beet, which are good at using light in the same cultivation area. The root system of beet (reaches up to 60 cm in depth) is deeper than that of cowpea (varies from 20 to 40 cm between the stages of growth and maturation of the grains), which is more superficial, resulting in more efficient use of space and time in environmental resources.

Another relevant factor that may have influenced the better performance of the intercropped system between cowpea and beet cultivars is the cowpea's ability to fix atmospheric nitrogen, which consequently improves soil fertility. According to Iqbal et al. (2019), the efficient use of resources is fundamental to obtaining better crop yields.

Thus, when two or more cultivars use different components of the productive system, use the same resource differently, or, in some way, explore different ecological niches, they strengthen the degree of complementarity between them. In this case, the intercropping system of this combination of cultivars produces more than its respective cultivars in monocropping (COSTA et al., 2017). According to Geraldi (1983), the most effective combinations between species in intercropped systems are those with high complementation between cultivars (called the high overall effect of intercropping).

As a result, the combination of cowpea cultivars with beet cultivars in an intercropped system can enable better use of environmental resources due to the effective interaction between inter- and intraspecific competition, thus increasing the productivity of the cultivars. According to Costa et al. (2017), this is possible when species have distinct ecological niches, maximizing the use of light and the absorption of nutrients and other resources.

Based on the results of the combined analysis of variance, no significant interaction was observed between the cowpea and beet cultivar combinations and cropping years in the economic efficiency indexes. There was also no significant difference between the cropping years in these indices; however, significant differences between the cowpea and beet cultivar combinations were observed (Table 3).

Table 3. F and mean values for gross income (GI), net income (NI), rate of return (RR), and corrected monetary advantage (CMA) from the combinations of cowpea and beet cultivars[(1)].

Sources of Variation	DF	GI R$ ha^{-1}	NI R$ ha^{-1}	RR R$	CMA R$ ha^{-1}
Blocks (Cropping years)	6	1.56^{NS}	1.55NS	1.56NS	2.07NS
Cropping years (Y)	1	3.47^{NS}	3.47NS	3.43NS	0.47**
Cultivar combinations (C)	7	2.46*	2.48*	2.50*	2.55*
Y x C	7	1.41^{NS}	1.41NS	1.40NS	1.68NS
Cropping years					
2016	-	33,385.64a	12,512.44a	1.60a	3299.49a
2017	-	30,086.80a	9213.61a	1.44a	3774.35a
CV (%)	-	22.31	25.17	22.33	28.70

(1) Means followed by different lowercase letters in the column differ from each other by the F test at a 5% probability.
** = P < 0.01; * = P < 0.05; NS = P > 0.05.

In general, in all tested cultivar combinations, there was a financial return from the studied intercropping systems, expressed by the values of the economic indicators evaluated (Table 4). This result leads us to infer that cowpea and beet intercropping are economically viable in semi-arid environments. The combination that registered the highest average value was that of the cultivar of cowpea BRS Guariba with the Fortuna beet cultivar.

Table 4. Mean values ($\overline{Y}$), differences between the means of the i-th combination and the maximum between the means of the other combinations (D) and the simultaneous confidence intervals (SCI) of these differences for the gross income (GI), net income (NI), rate of return (RR), and corrected monetary advantage (CMA) from the combinations of cowpea and beet cultivars.

Cultivar combinations		GI				NI			
		$\overline{Y}$	D	SCI		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	33,233.06	−1759.26	−9843.72	6325.20	12,276.27	−1926.45	−10,010.91	6158.01
BRS Tumucumaque	Fortuna	33,817.33	−1174.99	−9259.45	6909.47	13,027.73	−1174.99	−9259.45	6909.47
BRS Cauamé	Early Wonder	30,792.18	−4200.14	−12,284.60	3884.32	9835.39	−4367.33	−12,451.79	3717.13
BRS Cauamé	Fortuna	28,008.05	−6984.27	−15,068.73	1100.19	7218.45	−6984.27	−15,068.73	1100.19
BRS Guariba	Early Wonder	32,254.92	−2737.40	−10,821.86	5347.06	11,298.13	−2904.59	−10,989.05	5179.87
BRS Guariba	Fortuna	34,992.32	1174.99	−6909.47	9259.45	14,202.72	1174.99	−6909.47	9259.45
BRS Itaim	Early Wonder	32,688.10	−2304.21	−10,388.67	5780.25	11,731.31	−2471.40	−10,555.86	5613.06
BRS Itaim	Fortuna	28,103.81	−6888.51	−14,972.97	1195.95	7314.21	−6888.51	−14,97297	1195.95
		RR				CMA			
		$\overline{Y}$	D	SCI		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	1.59	−0.10	−0.48	0.29	3991.81	−2290.84	−5152.65	570.96
BRS Tumucumaque	Fortuna	1.63	−0.06	−0.44	0.33	4481.76	−1800.89	−4662.69	1060.91
BRS Cauamé	Early Wonder	1.47	−0.21	−0.60	0.17	2221.12	−4061.53	−6923.33	0.00
BRS Cauamé	Fortuna	1.35	−0.34	−0.72	0.05	2284.78	−3997.86	−6859.67	0.00
BRS Guariba	Early Wonder	1.54	−0.14	−0.53	0.24	2861.93	−3420.72	−6282.52	0.00
BRS Guariba	Fortuna	1.68	0.06	−0.33	0.44	6282.65	1800.89	−1060.91	4662.69
BRS Itaim	Early Wonder	1.56	−0.12	−0.51	0.26	3974.04	−2308.61	−5170.41	553.20
BRS Itaim	Fortuna	1.35	−0.33	−0.72	0.06	2197.28	−4085.36	−6947.17	0.00

The differences in climatic conditions between the cropping years were not sufficient to provide a significant difference in the economic efficiency rates evaluated. The agronomic–biological performance of the combination of the cultivar BRS Guariba with the cultivar Fortuna showed economic superiority among the tested combinations.

Part of this economic gain is due to the resulting interaction between cultivar BRS Guariba and cultivar Fortuna, which converts into mutually beneficial effects, thus reducing the use of external inputs. Some of the factors of this interaction that can be highlighted are the intra- and interspecific competitions exercised by the cultivars on the natural resources present in the soil and in the external environment.

The economic results obtained showed that the cultivars BRS Guariba and Fortuna showed spatial and temporal complementarity. According to Nasar et al. (2019), this complementarity is essential for maximizing the use of available resources in the horizontal and vertical planes above and below the ground. Therefore, there was better use of natural resources because, in intercropping, the cultivated species usually differ in height and in the distribution of leaves in space, among other morphological characteristics that can lead plants to compete for light energy, water, and nutrients (VIEGAS NETO et al., 2012). This complementarity is expressed in economic performance.

No significant interaction was observed between the cowpea and beet cultivar combinations and cropping years in the competition indexes (Table 5). However, a significant difference between the cropping years was recorded only in the aggressivity of the crops, with cropping year 2017 providing greater competition indexes.

Table 5. F and mean ($\overline{Y}$), differences between the means of the i-th combination and the maximum between the means of the other combinations (D), and the simultaneous confidence intervals (SCI) of these differences for the competitive ratio (CR) from the combinations of cowpea and beet cultivars, for aggressivity of beet cultivars (A_{bc}) over cowpea cultivars and for aggressivity of cowpea cultivars (A_{cb}) over beet cultivars[(1)].

Sources of Variation	DF	CR	A_{bc}	A_{cb}
Blocks (Cropping years)	6	1.52^{NS}	0.93^{NS}	0.93^{**}
Cropping years (Y)	1	0.10^{NS}	11.06^{**}	11.06^{**}
Cultivar combinations (C)	7	2.50^{*}	2.58^{*}	2.58^{*}
Y x C	7	1.35^{NS}	1.00^{NS}	1.00^{NS}
Cropping years				
2016	–	2.72a	0.49b	−0.49b
2017	–	2.63a	0.99a	−0.99a
CV (%)	–	29.40	22.23	22.23

Cultivar combinations		CR				A_{bc}			
		$\overline{Y}$	D	SCI		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	2.33	−0.99	−2.44	0.46	0.60	−0.51	−1.21	0.20
BRS Tumucumaque	Fortuna	2.35	−0.96	−2.41	0.48	0.72	−0.39	−1.09	0.32
BRS Cauamé	Early Wonder	2.65	−0.67	−2.12	0.77	0.68	−0.43	−1.13	0.28
BRS Cauamé	Fortuna	2.70	−0.62	−2.07	0.82	0.90	−0.20	−0.91	0.50
BRS Guariba	Early Wonder	3.32	0.37	−1.07	1.82	1.11	0.20	−0.50	0.91
BRS Guariba	Fortuna	2.94	−0.37	−1.82	1.07	0.87	−0.24	−0.94	0.47
BRS Itaim	Early Wonder	2.22	−1.10	−2.55	0.35	0.41	−0.69	−1.40	0.01
BRS Itaim	Fortuna	2.90	−0.41	−1.86	1.03	0.63	−0.48	−1.19	0.22

		A_{cb}			
		$\overline{Y}$	D	SCI	
BRS Tumucumaque	Early Wonder	−0.60	−0.19	−0.89	0.52
BRS Tumucumaque	Fortuna	−0.72	−0.31	−1.01	0.40
BRS Cauamé	Early Wonder	−0.68	−0.27	−0.97	0.44
BRS Cauamé	Fortuna	−0.90	−0.49	−1.20	0.21
BRS Guariba	Early Wonder	−1.11	−0.69	−1.40	0.01
BRS Guariba	Fortuna	−0.87	−0.46	−1.16	0.25
BRS Itaim	Early Wonder	−0.41	0.19	−0.52	0.89
BRS Itaim	Fortuna	−0.62	−0.21	−0.92	0.49

[(1)] Means followed by different lowercase letters in the column differ from each other by the F test at a 5% probability.
** = $P < 0.01$; * = $P < 0.05$; NS = $P > 0.05$.

The highest mean values for CR and A_{bc} were registered in the combination of cowpea cultivar BRS Guariba and beet cultivar Early Wonder. These results indicate that the Early Wonder beet cultivar, when in combination with the cowpea cultivar BRS Guariba, presented the greatest competition among the tested combinations. It can also be observed that the confidence interval for this combination has a large part of the positive values, leading us to infer that this combination is the most competitive among those evaluated and to state that this combination was the one that better used the environmental resources available in relation to the other combinations.

However, the highest mean value of A_{cb}, as well as the greatest difference between the means of the i-th combination and the maximum between the means of the other combinations, was recorded in the combination of cultivar BRS Itaim with cultivar Early Wonder. A lower competition index value was obtained by combining the cultivar BRS Itaim with cultivar Early Wonder, resulting in low agronomic and economic efficiency, and the lowest agroeconomic efficiency among the tested combinations.

The aggressiveness index of beet in the tested combinations was positive, and that of cowpea was negative. This means that beet was the dominant crop, and cowpea was the dominant crop in the intercropped system evaluated.

In this study, cowpea plants occasionally shaded part of the beet plants in the side rows of the strip. However, this situation did not interfere with the productivity of the beet culture. In an intercropping system, the environment of plants in relation to shading generally needs adjustments to avoid strong interspecific competition. Therefore, in this research, all combinations of cowpea cultivars with beet cultivars were tested in strip-intercropping with four rows of cowpea alternating with four rows of beet to minimize competition for light. Research conducted with cowpea intercropped with sorghum (OSENI; ALIYU, 2010) revealed that cowpea behaved as a dominated crop, in agreement with the behavior observed in this research, where cowpea was associated with beet.

CONCLUSIONS

The highest agro-bioeconomic efficiency of the tested intercropping systems was achieved in the combination of the cowpea cultivar BRS Guariba and the beet cultivar Fortuna. Beet behaved as the dominant crop and cowpea as the dominated crop in all evaluated intercropping systems. The indexes and indicators determined demonstrated the complementarity and sustainability of the combination of cowpea cultivar BRS Guariba with beet cultivar Fortuna.

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