Acta Scientiarum

http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v44i1.55146

CROP PRODUCTION

Bio-agroeconomic returns in beet-cowpea intercropping by optimization of population densities and spatial arrangements

Aridênia Peixoto Chaves[1], Francisco Bezerra Neto[1], Jailma Suerda Silva Lima[1], Josimar Nogueora Silva[2], Elizangela Cabral Santos[1], Renato Leandro Costa Nunes[3*] and Vitor Abel da Silva Lino[1]

[1]Departamento de Ciência Agronômicas e Florestais, Universidade Federal Rural do Semi-Árido, Av. Costa e Silva, 572, 50625-900, Mossoró, Rio Grande Norte, Brazil. [2]Secretaria de Agricultura do Município de Belém do Brejo do Cruz, Belém do Brejo do Cruz, Paraíba, Brazil. [3]Instituto Federal do Ceará, Limoeiro do Norte, Ceara, Brazil. *Author for correspondence. E-mail: renatoleandro.ce@hotmail.com

ABSTRACT. One of the great challenges of the beet and cowpea cultivation in crop association is to maintain their productivity as that of their sole counterparts in semi-arid environment. In this context, the objective of this work is to assess whether there is bio-agroeconomic return in associations of beet-cowpea by the optimization of population densities and spatial arrangements of the component crops. Experiments were performed in randomised complete block designs with treatments arranged in a 4 × 3 factorial scheme, with four replications. The first factor was the population densities of cowpea (100, 80, 60, and 40% of the recommended population in single crop - RPSC) in association with beet, and the second factor was the spatial arrangements (2:2, 3:3, and 4:4), formed by beet (B) rows alternating with cowpea (C) rows. The competition and agronomic indices evaluated were aggressiveness, competitive ratio, land equivalent ratio, actual yield loss, intercropping advantage and the productive efficiency index. The economic indicators evaluated were gross income, net income, rate of return and profit margin. High agro-economic efficiency can be obtained in the cultivation of beet and cowpea intercropping when well-managing the factors of production, population densities and spatial arrangement of the component crops. The greatest agro-economic return of the cowpea and beet intercropping was obtained in the population densities of 40 and 100% of RPSC for cowpea and beet, respectively. The 2:2 spatial arrangement between beet and cowpea crops was the one with the best productive performance and higher indicators of economic return. The cowpea was the dominant crop while the beet was dominated.

Keywords: *Beta vulgaris*; *Vigna unguiculata*; intraspecific and interspecific competition; sustainability.

Received on August 7, 2020.
Accepted on April 14, 2021.

Introduction

The intercropping systems are components of sustainable agriculture in Brazil, especially those that involve vegetable crops. They are used mainly in rural communities, and they consist of the spatial and temporal combination of two or more crops in the same area (Sediyama, Santos, & Lima, 2014). When these crops are compatible from the agronomic point of view, beneficial biological interactions occur between them, and thus the optimisation of production factors, such as population densities, spatial arrangements and fertilization increase their yields. Among the crops that can be successfully intercropped are cowpea and beet, as these crops are distinguished in their architecture and exploitation of natural resources, and also due to biological, nutritional, economic and social reasons, representing an alternative for food production and income for vegetable producer.

It is known that population density together with the spatial arrangement, when properly managed, intervenes in the spatial and temporal complementarity and competition between crops in the intercropping, thus providing an increase in productivity and efficiency of the system. In addition to promoting a series of changes in plant growth and development, dictated by intra- and interspecific competition and by environmental resources, it affects the production of the crops and their components (Sugasti, Junqueira, & Saboya, 2013).

However, the various possibilities of adequate plant spacing and density are referred to as plant arrangement, i.e. the configuration as the plants are allocated in the area. Theoretically, this configuration, when in ideal density, promotes increases in crop productivity, resulting from the complementary exploitation of the environmental resources below and above the ground through the better arrangement of the plants, thus minimising the effects of intra- and interspecific competition by resources (Pinto, Pinto, & Pitombeira, 2012).

One of the questions that has been asked is how to quantify the agronomic, economic and competition advantages between cultures arising from the interaction between them in the intercropped system. Cecílio Filho, Bezerra Neto, Rezende, Grangeiro, and Lima (2013), report that several indices have been developed in order to quantify the competition and agro-economic advantages in intercropping systems.

Among these indices, are the aggressivity (A), competitive ratio (CR), land equivalent ratio (LER), actual yield loss (AYL) (Cecílio Filho, Bezerra Neto, Rezende, Barros Júnior, & Lima, 2015), productive efficiency index (PEI), score of the canonical variable (Z) and the economic indicators of gross income (GI), net income (NI), rate of return (RR) and profit margin (PM) (Lima et al., 2014; Oliveira et al., 2015).

Studies involving the evaluation of the intercropping systems of vegetables through indices of competitive ability and biological efficiency have been carried out by Cecílio Filho et al. (2015), who when studying the efficiency of the cucumber and lettuce intercropping through biological and agroeconomic indices, determined the advantages of intercropping in relation to a single crop. Batista et al. (2016b) evaluated the bio-agroeconomic returns of the arugula and carrot intercropping in different population densities and obtained greater agroeconomic efficiency during the intercropping of these vegetables in the population combination of 40% of carrot RPSC with 100% of arugula RPSC.

In this context, the objective of this work is to assess whether there is bio-agroeconomic return in associations of beet-cowpea by the optimization of population densities and spatial arrangements of the component crops.

Material and methods

The present study was carried out in different areas of the Rafael Fernandes experimental farm of the *Universidade Federal Rural do Semi-Árido* (UFERSA), Mossoró, Rio Grande do Norte State, Brazil (5°11' S, 37°20' W, 18 m altitude) in the second halves of 2016 and 2017. The climate of the region is semi-arid and, according to Köppen's climatic classification scheme, called 'BShw', dry and very hot. There are two seasons: a dry season from June to January and a rainy season from February to May (Almeida et al., 2015), reaching average maximum temperatures between 32.1 and 34.5°C and minimum averages between 21.3 and 23.7°C, with June and July the coldest months and average annual precipitation around 685 mm.

The soils of the experimental areas were classified as typical Distrophic Red Argisol (Rêgo, Martins, Silva, Silva, & Lima, 2016) and the results of analyses of samples taken from these soils are shown in Table 1.

Table 1. Chemical analyses of soils before incorporation of the *C. procera* biomass in the first and second cropping year of the experimental areas.

Before the incorporation of *C. procera* biomass													
Experimental areas	N	pH	EC	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cu	Fe	Mn	Zn
	g kg^{-1}	(water)	ds m^{-1}	g kg^{-1}	mg dm^{-3}			cmol$_c$ dm^{-3}		mg dm^{-3}			
Soil 1	0.51	7.46	1.77	3.64	63.3	60.0	17.0	2.09	0.58	0.19	2.03	19.43	6.21
Soil 2	0.42	6.60	0.10	3.65	34.2	69.2	19.0	3.10	0.80	0.29	2.86	11.40	7.35

N-Nitrogen; pH-Hydrogenionic potential; EC-Electrical conductivity; O.M.-Organic matter; P-Phosphorus; K^+-Potassium; Na^+-Sodium; Ca^{2+}-Calcium; Mg^{2+}-Magnesium; Cu- Copper; Fe-Iron; Mn-Manganese and Zn-Zinc.

The experimental design was in randomised blocks with treatments arranged in a 4 × 3 factorial scheme, with four replications. The first factor was the population densities of cowpea of 40, 60, 80, and 100% of the recommended population in single crop (RPSC) in association with beet, and the second factor was the three spatial arrangements between the component cultures (2:2, 3:3, and 4:4), formed from rows of beet (B) alternating with rows of cowpea (C), during two cropping years.

The recommended planting density in the region for beet in a single crop is 500,000 plants per hectare (Batista, Bezerra Neto, Silva, Ambrosio, & Cunha, 2016a), and for cowpea, the rate is 200,000 plants per hectare (Costa et al., 2017). The cultivars of beet and cowpea planted were 'Early Wonder' and 'BRS Itaim'. The "Early Wonder" is a cultivar of open pollination, cycle ranging from 60 to 75 days, with tuberous root of globular shape that grows almost to the surface of the soil, has a markedly sweet flavour, purple colour and good acceptance. In experimental conditions, their productivity in the region varies from 15 to 40 t ha^{-1}. The cowpea cultivar "BRS Itaim" has grains of white color, subclass fradinho, reniforms, with halo of black color, denominated blackeye. The plants show type I determined growth, erect architecture and good lodging tolerance. Its cycle varies from 55 to 70 days and has good acceptance and average productivity in the region around 1.16 t ha^{-1} (Medeiros, Demartelaere, Lima, Silva, & Pádua, 2019).

The intercropping systems were established in alternating strips, using 50% of the area with beet and the other 50% of the area with cowpea, flanked by two rows bordering each crop on each side. The total area of the plots in the spatial arrangements 2:2, 3:3, and 4:4 were 2.40, 3.00, and 3.60 m², respectively, with harvest areas of 1.00, 1.50, and 2.00 m². The planting spacing in the intercropping was 0.25 m between rows, and within the rows of cowpea the spacing varied according to the population densities studied, which were 0.10; 0.12; 0.17, and 0.25 m, respectively. The spacing between beet plants was 0.04 m.

In each block, single parcels of beet and cowpea crops were planted to obtain the intercropping efficiency indices. For beet, the total plot area was 1.44 m^2, with a harvest area of 0.80 m^2, and spacing was 0.20 × 0.10 m. For the cowpea, the total area was 3.60 m^2, with a harvest area of 2.00 m^2, and spacing was 0.50 × 0.10 m.

A green manuring with roostertree [*Calotropis procera* (Ait) R. Br.] was carried out in all the experimental plots, and the collection of this fertiliser was carried out near the city of Mossoró, Rio Grande do Norte State, Brazil. The plants were cut manually with the aid of machete, extracting only the green part of the plant. Afterwards, the material was crushed in mechanical forage and submitted to the drying process in full sun until reaching the point of phenation. Samples of this material were collected and sent to the Laboratory of Soil Fertility and Plant Nutrition of UFERSA, where the chemical analyses were performed, the results of which are shown in Table 2.

Table 2. Macro and micronutrient contents of the *C. procera* biomass incorporated into the soil in the 2016 and 2017 cropping years.

Cropping years	Macronutrient contents in the green manure (g kg^{-1})					Micronutrient contents in the green manure (mg kg^{-1})					C/N ratio
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Na	
1	18.40	3.10	14.50	16.30	13.50	100.50	21.75	37.88	3.85	608.5	25:1
2	15.30	3.66	25.60	8.60	4.32	94.30	16.24	29.77	3.04	207.3	25:1

N-Nitrogen, P-Phosphorus, K-Potassium, Ca-Calcium, Mg-Magnesium, Fe-Ferro, Mn-Manganese, Zn-Zinc, Cu-Copper, Na-Sodium, and C/N-Carbon/nitrogen ratio.

Two incorporations of the green manure into the intercropped plots and in the cowpea and beet plots in single crops were carried out, with 50% of the *C. procera* amounts being incorporated 20 days before planting and 50% incorporated at 44 days after sowing (DAS), in optimised amounts in the region for the respective cropping systems. The experimental plots of the beet-cowpea intercropping system were fertilized with the amount of 47 t ha^{-1} of *C. procera* biomass, and the plots of beet and cowpea in single crops with the biomass amounts of 39 and 59 t ha^{-1}, respectively, based on researches carried out with this green manure previously (Ribeiro et al., 2020; Morais et al., 2018).

During the experiment, watering was carried out in two irrigation shifts (morning and afternoon), providing a water sheet of approximately 8 mm d^{-1}. The planting of the component crops was carried out on September 14th, 2016 and October 4th, 2017, with direct sowing at two centimetres depth. After the emergence of the crops, the thinning occurred at 10 and 15 days for beet and cowpea, respectively, leaving one plant per hole. During the cultivation cycle, two manual weedings were made to control invasive plants, being the first performed at 25 DAS and the other at 45 DAS.

No chemical pest and disease control methods were required, and no other fertilizer input had been used besides green manure. The vegetable cultivation practices used in this research, such as intercropping of crops, soil management with the use of green manure and spontaneous plant management using manual grubbing control, are those recommended for the cultivation of vegetables in the organic system in the region (Sediyama et al., 2014).

Beet harvesting was carried out 70 days after sowing (DAS) in both years, while harvesting of cowpea was carried out with four harvests in the range of 55-65 days after planting in their cropping years.

The indices evaluated were aggressivity (A), competitive ratio (CR), land equivalent ratio (LER), actual yield loss (AYL), intercropping advantage (IA) and productive efficiency index (PEI). The economic indicators evaluated were gross income (GI), net income (NI), rate of return (RR), and profit margin (PM).

Aggressivity (A) was determined by the expression used by Cecílio Filho et al. (2015):

$$A_{bc} = (Y_{bc}/(Y_{bb} \times Z_{bc})) \times (Z_{cb}/Z_{bc})$$

and

$$A_{cb} = [(Y_{cb}/(Y_{cc} \times Z_{cb}) - (Y_{bc}/(Y_{bb} \times Z_{bc}) (Z_{cb}/Z_{bc}),$$

where: A_{bc} is the aggressivity of beet in intercropping with the cowpea, A_{cb} is the aggressivity of cowpea in intercropping with beet, Y_{bc} is the commercial productivity of beet roots intercropped with the cowpea (classified productivity of the roots based on the root diameter (RD) and classified into in extra (RD > 4 and < 5 cm), extra A (RD ⩾ 5 and < 6 cm), extra AA (RD ⩾ 6 and < 7 cm), and large (RD > 7 cm), Y_{cb} is the productivity of the cowpea intercropped with the beet, Y_{bb} is the commercial productivity of beet in single crop, Y_{cc} is the productivity of the cowpea in single crop, Z_{bc} is the proportion of beet planting in intercropping with the cowpea and Z_{cb} is the proportion of planting of cowpea in intercropping with beet. When A_{bc} is greater than zero, the ability of the beet crop exceeds the ability of the cowpea in the intercropping, or vice versa.

The competitive ratio of beet (CR_b) and cowpea (CR_c) was calculated by the following expressions (Cecílio Filho, et al., 2013):

$CR_b = [(Y_{bc}/Y_{bb})/(Y_{cb}/Y_{cc})]\times(Z_{cb}/Z_{bc})$

and

$CR_c = [(Y_{cb}/Y_{cc})/(Y_{bc}/Y_{bb})]\times(Z_{bc} /Z_{cb})$. Y_c, Y_b, Y_{bc}, Y_{cb}, Z_{cb} e Z_{bc}

are defined in the aggressivity (A) description.

Land equivalent ratio (LER) is defined as the relative area of land under isolated planting conditions that is required to provide the productivities reached in the intercropping (Gebru, 2015). It was calculated by the following expression:

$(Y_{bc}/Y_{bb}) + (Y_{cb}/Y_{cc})$,

where: Y_{bc} is the productivity of commercial roots of beet intercropped with cowpea, Y_{bb} is the productivity of commercial beet roots in single crop, Y_{cb} is the productivity of green grains of cowpea intercropped with beet and Y_{cc} is the productivity of green grains of cowpea in single crop.

The actual yield loss (AYL), according to Cecílio Filho et al. (2015) is defined by the following expression:

$AYL = AYL_b + AYL_c$; $AYL_b= [\{(Y_{bb}/Z_{bc})/(Y_{bb}/Z_{bb})\} - 1]$

and

$AYL_c= [\{(Y_{cb}/Z_{cb})/(Y_{cc}/Z_{cc})\} - 1]$,

where: AYL is the actual yield loss of the system, AYL_b is the actual yield loss of beet, AYL_c is the actual yield loss of cowpea, Z_{cc} is the proportion of cowpea planting in single crop, Z_{bb} is the proportion of beet planting in single crop, Z_{cb} is the proportion of planting of cowpea in intercropping with beet and Z_{bc} is the proportion of beet planting in intercropping with cowpea.

Y_{cc}, Y_{bb}, Y_{bc}, Y_{cb}, Z_{cb}, $Z_{bc,}$ Z_{bb} e $Z_{cc,}$

are defined in the aggressivity (A) description.

The intercropping advantage (IA) was determined by the formula:

$IA = IA_b + IA_c$, where IA_b =

Intercropping advantage of beet; IA_c = Intercropping advantage of cowpea;

$IA_b = AYL_b \times P_b$ and $IA_c = AYL_c \times P_c$,

where AYL_b and AYL_c are defined in the description of the actual yield loss (AYL). P_b is the price of beet in R$ kg^{-1}, and P_c is the price of cowpea in R$ kg^{-1}. The mean price paid in December 2016 and 2017 were R$ 2.50 and 2.30 kg^{-1} for beet and R$ 7.50 and 5.60 kg^{-1} for cowpea, respectively. The current exchange rate of the US dollar was $1 = R$ 3.30 and 3.31, in December 2016 and 2017.

In the calculation of the productive efficiency index of each treatment, the DEA model was used with constant returns to the scale (Mello & Gomes, 2013), since there are no differences of significant scales. This model has the mathematical formulation in which X_{ik} is the value of the input i (i = 1,..., s), for the treatment k (k = 1,..., n), Y_{jk} is the value of output j (j = 1,..., r), for treatment k and vi and uj are the weights assigned to inputs and outputs, respectively; O is the treatment under analysis.

$$\text{Max} \sum_{i=1}^{r} v_i x_{io}$$

$$\sum_{j=1}^{s} u_j y_{jo} \ = 1 \sum_{j=1}^{s} u_j y_{jk} \ _- \sum_{i=1}^{r} v_i x_{ik} \leq 0, \mathrm{k} = 1, \dots, \mathrm{n}$$

$$\mathrm{u_j}, \mathrm{V_i} \ \geq \mathrm{o}, \mathrm{i} = 1, \dots, \mathrm{s}, \mathrm{j} = 1, \dots, \mathrm{r}.$$

The evaluation units were the treatments (intercrops), and were a total of twelve. As outputs, the productivities of beet and cowpea were used. In order to evaluate the yields of each plot, it was considered a single resource with unit level, since the outputs incorporated the possible inputs. This model is equivalent to the additive multicriteria model, with the particularity that the alternatives themselves attribute weights to each criterion, ignoring any opinion of eventual decision makers. That is, the DEA is used as a multicriteria tool and not as a measure of classical efficiency. In the modelling of this study, the rate of return as input was used.

The efficiency of the intercropping system was also determined by the canonical variable score (Z), obtained through the bivariate analysis of variance of beet and cowpea productivities.

The costs were determined and verified at the end of the production cycle in December 2016 and 2017 by performing the ex-post cost analysis. The cost modality analysed in this research represented the total expenditures (total costs) per hectare of cultivated area, which included services provided by stable capital, that is, the contribution of working capital and the value of alternative costs (also called costs of opportunity). Similarly, the revenues referred to the value of the production of one hectare that was measured, according to the price paid to the producer in December 2016 and 2017, which corresponded to R$ 2.50 and 2.30 kg^{-1} for beet and R$ 7.50 and 5.60 kg^{-1} for cowpea, respectively.

Gross income (RB) was determined by the production value obtained per hectare and the price paid to the producer at the market level in the region in the month of December in the years 2016 and 2017. Net income (RL) was calculated subtracting the gross income (RB) per hectare, of the total costs (TC) of production.

The rate of return (RR) was expressed by the ratio between gross income (GI) and total costs (TC), that is, RR = GI/TC, which corresponded to the number of reals (R$) for each real invested in beet intercropping and cowpea depending on the treatments applied. In addition to this, the profit margin (PM) consisted of the ratio between net income (NI) and gross income (GI), expressed as a percentage.

Univariate analyses of variance were performed in the evaluation of the characteristics of the component cultures and the agroeconomic efficiency indices of the intercropping, using SISVAR software (Ferreira, 2011). The procedure for adjusting response curves for the different population densities was performed using Table Curve software (Jandel Scientific, 1991). The Tukey test at 5% probability was used to compare the means between the spatial arrangements.

Results and discussion

The mean values for competition indices: competitive ratio (CR), actual yield loss (AYL), and aggressivity (A) are presented in the Table 3 and Figure 1. A significant interaction was observed between the cropping years and the population densities of cowpea in the competitive ratios of beet (CR_b) and cowpea (CR_c) and in the actual yield loss of cowpea (AYL_c).

When partitioning the competition indices of the cropping years within each cowpea population density, beet had a higher competitive ratio in the first cropping year only in the 40% RPSC cowpea density, different from the competitive ratio of cowpea, which manifested this behaviour in the second cropping year (Table 3). In the actual yield loss of cowpea, it was observed that their mean values in the second year stood out from that the first year in all the population densities of cowpea studied. Significant differences were recorded between the cropping years for the actual yield loss of the beet, with the means of the second year standing out from the first year (Table 3).

When analysing the spatial arrangements, no significant differences were observed between the aggressivity of the beet and cowpea, and in the competition ratio and actual yield loss of the beet. In contrast, the 2:2 arrangement stood out from the others in the competitive ratio and in the actual yield loss of cowpea.

Table 3. Competitive ratio of the beet (CR_b) and cowpea (CR_c), actual yield loss of the beet (AYL_b) and cowpea (AYL_c), aggressivity of the beet (A_b) and cowpea (A_c) of intercrops of beet and cowpea, in two cropping years and different spatial arrangements.

A. Mean values in the cropping years and spatial arrangements						
Cropping years	A_b	A_c	CR_b	CR_c	AYL_b	AYL_c
1	-0.49 a	0.49 a			0.43 b	
2	-0.41 a	0.41 a			0.77 a	
Spatial Arrangements						
2:2	-0.55 a	0.55 a	1.15 a	1.02 a	0.59 a	0.89 a
3:3	-0.41 a	0.41 a	1.25 a	0.85 b	0.58 a	0.66 b
4:4	-0.38 a	0.38 a	1.36 a	0.89 ab	0.63 a	0.76 ab
B. Partitioning of the cropping years within population densities						
Cowpea population densities (%RPSC)	CR_b		CR_c		AYL_c	
	Year					
	1st	2nd	1st	2nd	1st	2nd
40	1.58 A	1.01 B	0.68 B	1.02 A	0.10 B	0.90 A
60	1.25 A	0.96 A	1.00 A	1.08 A	0.56 B	0.93 A
80	0.83 A	0.85 A	1.32 A	1.21 A	0.69 B	1.08 A
100	0.77 A	0.92 A	1.39 A	1.19 A	0.77 B	1.12 A

*Means followed by different lowercase letters in the column or upper case in the row differ statistically from each other by the F or Tukey test at the 5% probability level.

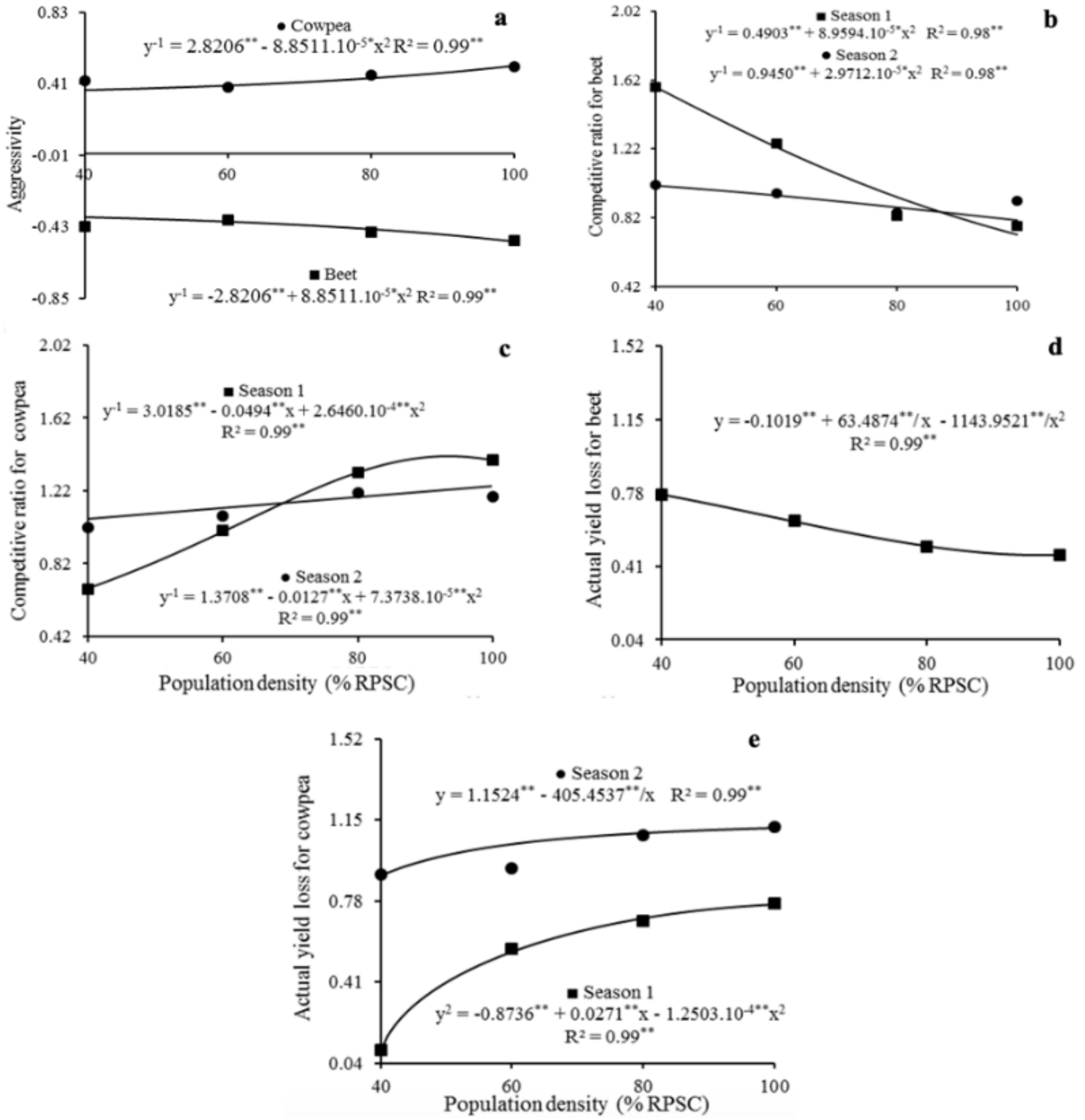

Figure 1. Aggressivity of the beet and cowpea (a), competitive ratio of the beet (b) and cowpea (c), actual yield loss of the beet (d) and cowpea (e) intercropped with beet in different population densities of cowpea and cropping years.

For the aggressivity of beet, a maximum value of -0.37 was observed in the 40% RPSC density of the cowpea, and it then decreased to the last density studied. The reverse behaviour was recorded in the aggressivity of cowpea, in which it obtained a maximum value of 0.52 at 100% of RPSC density of cowpea (Figure 1a).

Decreasing behaviour was observed in the partitioning of the competitive ratio of beet as a function of the increase in the population densities of the cowpea, with maximum values of 1.56 and 1.01 at the 40% RPSC density of cowpea in cropping years 1 and 2, respectively (Figure 1b).

Increasing behaviours were observed in the partitioning of the competitive ratio and actual yield loss of the cowpea with the increase of the population densities of the cowpea, with maximum values of 1.40 and 0.77 for the densities of 93.44 and 100% of cowpea RPSC in the first cropping year, and up to the maximum values of 1.21 and 1.11 in the densities of 86.00 and 100% of cowpea RPSC in the second year, respectively (Figure 1c and e). For the actual yield loss of the beet, a maximum value of 0.77 was observed at the density of 40% of the cowpea RPSC, and then it decreased up to the last density studied (Figure 1d).

Competition is one of the main factors that have a significant impact on the growth rate and yield of the crops used in the intercropping when compared to those of monocultures. In the present study, a number of indices such as aggressivity (A), competitive ratio (CR) and real yield loss (AYL) have been used to quantify the beneficial competitive effects in different planting patterns (Cecílio Filho et al., 2013), since these indices facilitate the description of competitive behaviour in intercropping systems. They have been used to evaluate the competition in the beet and cowpea intercropping, where the cowpea population varied in different patterns of density, spatial arrangement of the component cultures and cropping years.

Based on the aggressivity, cowpea was the dominant crop and the beet was the dominated crop. Regardless of the spatial arrangement, the interaction between cowpea population densities and cropping years on the competitive ratio of the two crops and on the actual yield loss of cowpea is partly due to differences in abiotic factors such as temperature, relative humidity and solar radiation from the cropping years, which provided a lower rate of competition in the lower population density of the cowpea on the dominated crop in the second cropping year and in the dominant crop in the less favourable cropping year. Thus, the lowest actual yield loss of both beet and cowpea was recorded during the less favourable cropping year, where the lowest interspecific competition was recorded.

The behaviour of the aggressivity and of the actual yield loss of the beet and cowpea as a function of the population densities of cowpea represents the interspecific complementarity between the component cultures in the intercropping in the cropping years (Cecílio Filho et al., 2015).

In relation to the competitive ratios, the maximum points found in the respective amounts represent the use of environmental resources, such as water, sunlight and nutrients with maximum efficiency (Nunes et al., 2018). According to Eskandari and Ghanbari (2010), the optimum point expresses the exact degree of competitiveness among species by indicating the number of times dominant species were more competitive than the dominated species. Thus, by observing the competitive ratio of both crops, the beet was the dominated crop, and the cowpea was the dominant crop in the intercropping. This shows that the beet had less capacity to compete for the environmental resources than the cowpea. According to Passos et al. (2019), the competitiveness of a crop is proportional to the increase of plant density in the studied area. In addition, the cowpea presents a rapid speed of emergency and initial growth, thus allowing a better use of environmental resources. In this way, with the increase of the population densities of the cowpea, it was verified that the competitive capacity of the beet decreased and that of the cowpea increased.

The positive values of actual yield loss of cowpea and beet indicate the accumulated advantage of the intercropping system in relation to monoculture. In addition, the partial values of this index followed the same tendency of the aggressivity and the competitive ratio, thus demonstrating superiority of the cowpea in relation to the beet crop. According to Cecílio Filho et al. (2015), this index provides more accurate information than the other indices on inter- and intraspecific competitions in intercropped systems.

This predominance can also be attributed to the morphological and physiological factors of cowpea, allowing it to use natural resources more efficiently. Similar results were obtained by Morais et al. (2018), studying the intercropping of vegetable cowpea and beet in which they verified that the cowpea was the dominant crop, whereas the beet was the dominated crop within the established intercropping. However, in spite of all the competition exercised by the cowpea, the beet did not suffer significant losses in its productivity in the intercropped system.

The mean values for agronomic/biological efficiency indices are presented in the Table 4 and Figure 2. A significant interaction was observed between the cropping years and the population densities of cowpea for the land equivalent ratio and intercropping advantage. When partitioning the land equivalent ratio and the intercropping advantage of the cropping years within each population density of cowpea, we can the mean values in the second year was superior that of the first year for all the population densities studied (Table 4).

Table 4. Land equivalent ratio (LER), productive efficiency index (PEI), intercropping advantage (IA) and score of the canonical variable (Z) of the intercropping of beet with cowpea in two cropping years and different spatial arrangements.

Cropping years	LER		PEI	IA	Z
1			0.83 b		1.00 b
2			0.88 a		1.15 a
Spatial Arrangements					
2:2	1.71 a		0.88 a	7.17 a	1.09 a
3:3	1.60 a		0.86 a	5.90 a	1.08 a
4:4	1.64 a		0.84 a	6.05 a	1.06 a
Partitioning of the cropping years within population densities					
Cowpea population densities (%RPSC)	LER		IA		
	Year 1	Year 2	Year 1	Year 2	
40	1.34 B	1.84 A	1.81 B	7.78 A	
60	1.50 B	1.86 A	4.08 B	7.76 A	
80	1.53 B	1.88 A	6.14 B	8.34 A	
100	1.55 B	1.72 A	6.60 A	8.51 A	

*Means followed by different lowercase letters in the column or upper case in the row differ statistically from each other by the F or Tukey test at the 5% probability level.

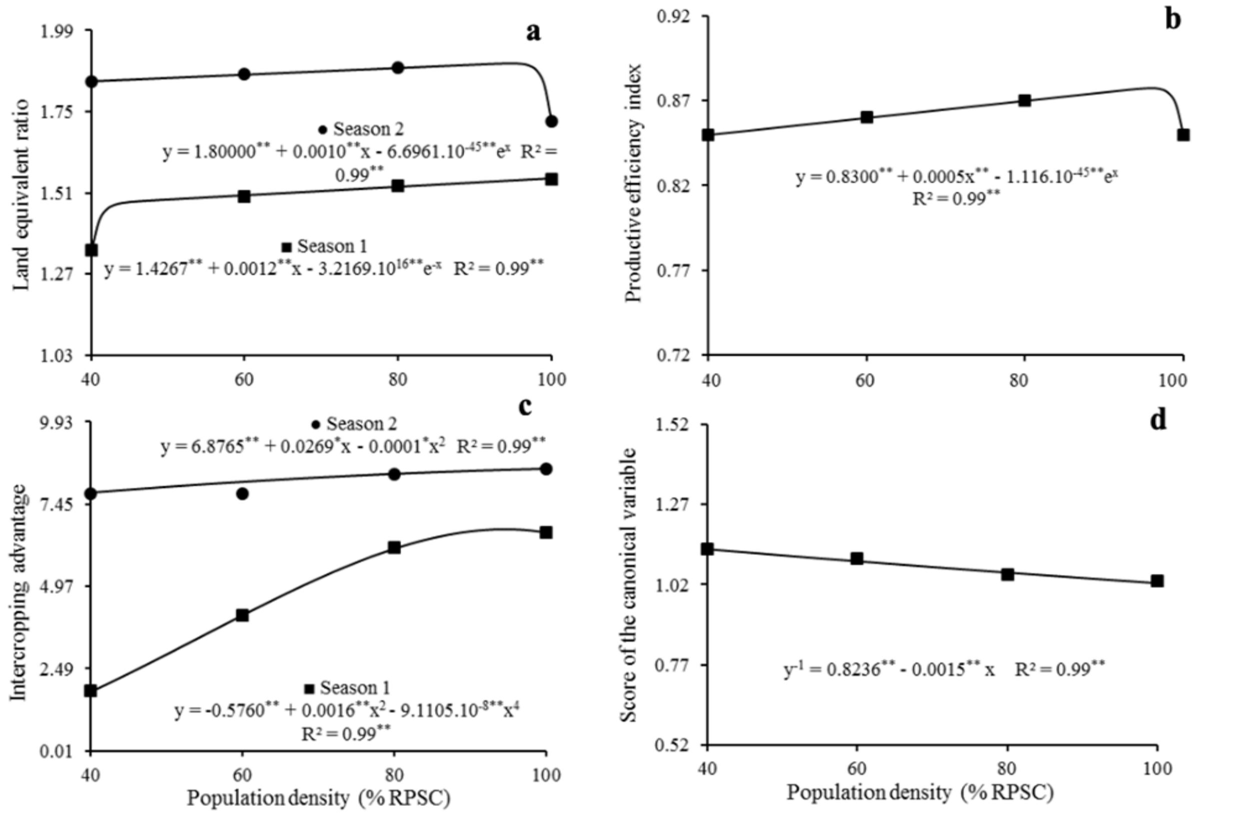

Figure 2. Land equivalent ratio (a), productive efficiency index (b), intercropping advantage (c) and score of the canonical variable (d) of cowpea intercropped with beet at different population densities of cowpea and cropping years.

Significant differences were recorded between the cropping years in the productive efficiency index, and the score of the canonical variable with the means of the second season stood out from the first year (Table 4). When analysing the spatial arrangements, no significant differences were observed between the studied agronomic/biological efficiency indices.

Crescent behaviour was observed in the partitioning of the land equivalent ratio and of the intercropping advantage within the population densities of cowpea tested, reaching maximum values of 1.55 and 6.45 at the densities of 100 and 94.56% of the cowpea RPSC in the first cropping year, and maximum values of 1.89 and 8.57 at the densities of 94.81 and 100% of cowpea RPSC in the second cropping year, respectively (Figure 2a and c).

Decreasing behaviour was observed for the score of the canonical variable as a function of the increase in population densities of the cowpea, with maximum values of 1.13 at the density of 40% of RPSC of cowpea (Figure 2d). The opposite behaviour was recorded for the productive efficiency index; it obtained a maximum value of 0.88 at the density of 95.90% of cowpea RPSC (Figure 2b). When studying the effect of spatial arrangements on agronomic indices, no significant differences were observed between them (Table 4).

The efficiency and advantage of an intercropped system depends fundamentally on the complementarity between the component cultures. Several factors may have a significant impact on the agronomic (yield) and biological (growth rate) of the component crops in intercropping. Among them are cultivated crop types, planting spatial arrangements, crops population densities, cropping years, among others (Ribeiro et al., 2017). Several indices have been developed to quantify advantages in intercropped systems; among them are the LER, IA, PEI, and the score of the canonical variable (Batista et al., 2016b; Cecílio Filho et al., 2013).

The LER and IA values we obtained were higher than unity, indicating the agronomic advantage of the intercropping systems. Its highest values were reached in the second cropping year, due in part to the higher content of potassium present in the green manure. It is known that this nutrient in the cowpea helps in the filling and growth of the grains and in both cultures helps in the formation and development of the roots, being able to provide plants with greater productive capacity (Oliveira et al., 2007; Bezerra Neto, Barreto, & Coelho, 2014/2015). LER optimisation was achieved in the second cropping year and IA in the first year, both in the same cowpea density of 95% RPSC. Based on this optimisation of the LER, we can verify that the beet and cowpea monocultures would require 89% more area to produce the equivalent in the intercropping system in one hectare (Gebru, 2015). These optimisation results translate well the best use of the environmental resources carried out in each planting year.

The productive efficiency index followed the same behaviour of the land equivalent ratio; its optimisation was achieved at the cowpea population density of 96% RPSC, practically similar to the LER that was of 95% RPSC. These results lead us to believe that the best efficiency and yield advantage of the beet-intercropped system with cowpea occurred around this population density of cowpea, regardless of the spatial arrangement used.

The behaviour of the canonical variable was dictated by the pressure of the population densities of the cowpea, decreasing the value of the score with the increase of the population density. Behaviour was completely different from that obtained by Ribeiro et al. (2017), when he intercropped carrot with cowpea in the same densities and spatial arrangements of this research and managed to optimise this score as a function of the population densities of cowpea. This difference in result is probably due to the tuberosity used, where the carrot is a larger cycle culture than the beet, thus allowing the best use of the environmental resources by the carrot and cowpea plants, consequently the optimisation was reached for this score.

Regarding the spatial arrangement of intercrops, the degree of rectangularity of each culture will be an important factor determinant of the efficiency with which the resources are used. It is often dependent on how "intimately" species are mixed. Although spatial arrangements and population densities are highly interdependent, at the same time, they can have distinct and separable effects depending on the type of cultures used. In this research, there was no significant interaction between spatial arrangements and population densities in the evaluated agronomic indices of beet and cowpea intercropping systems, indicating that, independently of the populations studied, the spatial arrangements behaved similarly.

In addition, with the proper management of the factors studied in this research, the achievement of efficiency and agronomic advantage in intercropping systems of beet and cowpea, may allow the producers that practice associations with these crops to obtain intercropping systems that are more efficient and of high agronomic yield.

The mean values for economic indicators are presented in the Table 5 and Figure 3. However, significant differences were recorded in all economic indicators between cropping years, with the highest average values found in the second cropping year (Table 5). On the other hand, significant differences were not recorded among the spatial arrangements for any of the indicators studied.

Table 5. Gross income (GI), net income (NI), rate of return (RR) and profit margin (PM) of the intercropping of beet with cowpea in two cropping years in different spatial arrangements.

Cropping years	GI	NI	RR	PM
1	39451.98 b	17127.89 b	1.77 b	41.87 b
2	49693.44 a	26904.10 a	2.18 a	53.46 a
		Spatial Arrangements		
2:2	44660.35 a	22130.56 a	1.71 a	48.18 a
3:3	44011.94 a	22003.84 a	1.60 a	47.82 a
4:4	44045.84 a	21713.60 a	1.64 a	46.98 a

* Means followed by different lowercase letters in the column differ statistically from each other by the F or Tukey test at the 5% probability level.

Decreased behaviour was observed for the indicators gross and net incomes, rate of return and profit margin as a function of the increase of population densities of the cowpea, with maximum values of R$ 46,212.64 and 23,806.80 ha^{-1} in addition to 2.06 and 49.88% for the density of 40% of RPSC of cowpea, respectively (Figure 3).

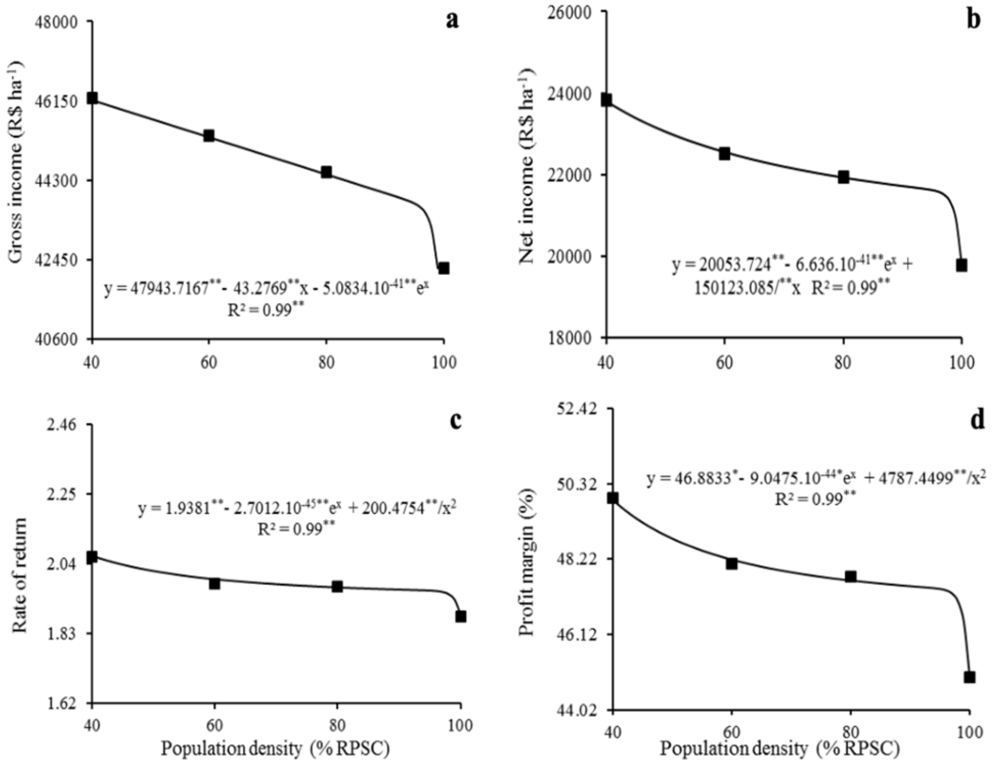

Figure 3. Gross income (a), net income (b), rate of return (c) and profit margin (d) of the intercropping of beet with cowpea at different population densities of cowpea.

In view of the information obtained in the competition and agronomic-biological indices, the question that arises is whether the efficiency and advantage obtained with the best management of the factors of production studied translated into advantage and economic financial efficiency.

The producer who practices intercropping with vegetables must have a guarantee of economic security regarding the practice of their cropping systems, and one of the ways to obtain information on the viability of this practice is to evaluate the intercropped systems through economic indices such as gross income, net income, rate of return and profit margin.

Based on the efficiency results of the agronomic-biological indices of beet and cowpea intercropping systems, it was observed that this efficiency was translated in terms of economic advantage. These results are due, in part, to the greater yields obtained in the second cropping year of cowpea and beet, as a result of the better efficiency in the use of environmental resources, as previously seen in the indices of competition and agronomic/biological efficiency.

Although there was no significant difference between the spatial arrangements, this result shows a compensatory economic behaviour of the spatial arrangements. That is, regardless of the spatial arrangement used, there will be no change in the economic difference of the intercropped systems. In the lower densities of cowpea, economic gains were obtained from beet production, which compensated for the lower productions of cowpea in these studied densities.

The results obtained in this study were superior to those found by Ribeiro et al. (2017), who evaluated the carrot and vegetable cowpea intercropping at different population densities, and found values for gross and net income, rate of return and profit margin of R$ 23,493.07 and 7,957.12 ha^{-1}; 1.49 and 32.73%, respectively. Among these indices, net income was the one that expressed the best economic value of intercropped cropping systems, since the production costs were deducted from it (Bezerra Neto, Porto, Gomes, Cecílio Filho, & Moreira, 2012). These indices also indicate that the agronomic-biological superiority obtained in the intercropping systems translated into economic advantage.

Conclusion

High agro-economic efficiency can be obtained in the cultivation of beet and cowpea intercropping when well-managing the factors of production, population densities and spatial arrangement of the component crops. The greatest agro-economic return of the cowpea and beet intercropping was obtained in the population densities of 40% and 100% of RPSC for cowpea and beet, respectively. The 2: 2 spatial arrangement between beet and cowpea crops was the one with the best productive performance and higher indicators of economic return. The cowpea was the dominant crop while the beet was dominated.

Acknowledgements

Special thanks are due to the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* for financial support and to the research group at the Department of Agronomic and Forest Sciences of the *Universidade Federal Rural do Semi-Árido*, which develops technologies for growing crops on family farms.

References

Almeida, A. E. S., Bezerra Neto, F., Costa, L. R., Silva, M. L., Lima, J. S. S., & Barros Júnior, A. P. (2015). Eficiência agronômica do consórcio alface-rúcula fertilizado com flor-de-seda. *Revista Caatinga*, *28*(3), 79-85.

Batista, M. A. V., Bezerra Neto, F., Silva, M. L., Ambrosio, M. M. Q., & Cunha, J. L. X. L. (2016a). Soil-plant attributes and beet production influenced by fertilization with species of Brazilian Caatinga. *Horticultura Brasileira*, *34*(1), 31-38.

Batista, T. M. V., Bezerra Neto, F., Porto, V. C. N., Barros Júnior, A. P., Silva, I. N., Silva, M. L., ... Oliveira, E. Q. (2016b). Bio-agro-economic returns from carrot and salad rocket as intercrops using hairy woodrose as green manure in a semi-arid region of Brazil. *Ecological Indicators*, *67*(1), 458-465.

Bezerra Neto, E., Barreto, L. P., & Coelho, J. B. M. (2014/2015). Considerações sobre nutrição mineral e o caso do feijão Vigna. *Anais da Academia Pernambucana de Ciências Agronômica*, *11-12*, 85-120.

Bezerra Neto, F., Porto, V. C. N., Gomes, E. G., Cecílio Filho, A. B., & Moreira, J. N. (2012). Assessment of agroeconomic indices in polycultures of lettuce, rocket and carrot through uni- and multivariate approaches in semi-arid Brazil. *Ecological Indicators*, *14*(1), 11-17. DOI: http://dx.doi.org/10.1016/j.ecolind.2011.07.006

Cecílio Filho, A. B., Bezerra Neto, F., Rezende, B. L. A., Barros Júnior, A. P., & Lima, J. S. S. (2015). Indices of bio-agroeconomic efficiency in intercropping systems of cucumber and lettuce in greenhouse. *Australian Journal of Crop Science*, *9*(12), 1154-1164. DOI: http://hdl.handle.net/11449/168331

Cecílio Filho, A. B., Bezerra Neto, F., Rezende, B. A., Grangeiro, L. C., & Lima, J. S. S. (2013). Indices of competition and bio-agroeconomic efficiency of lettuce and tomato intercrops in greenhouses. *Australian Journal of Crop Science*, *7*(6), 809-819.

Costa, A. P., Bezerra Neto, F., Silva, M. L., Lima, J. S. S., Barros Júnior, A. P., & Porto, V. C. N. (2017). Intercropping of carrot x cowpea-vegetables: evaluation of cultivar combinations fertilized with roostertree. *Revista Caatinga*, *30*(3), 633-641.

Eskandari, H., & Ghanbari, A. (2010). Effect of different planting pattern of wheat (*Triticum aestivum*) and bean (*Vicia faba*) on grain yield, dry matter production and weed biomass. *Notulae Scientia Biologicae*, *2*(4), 111-115. DOI: http//doi.org.10.15835/nsb.2.4.4824

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039-1042. DOI: https://doi.org/10.1590/S1413-70542011000600001

Gebru, H. (2015). A review on the comparative advantages of intercropping to mono-cropping system. *Journal of Biology, Agriculture and Healthcare*, *5*(9), 1-13. DOI: https://www.iiste.org/Journals/index.php/JBAH/article/view /22307

Jandel Scientific. (1991). *Table Curve*: curve fitting software. Corte Madera, CA: Jandel Scientific.

Lima, V. I. A., Lima, J. S. S., Bezerra Neto, F., Santos, C. S., Rodrigues, G. S. O., & Paula, V. F. S. (2014). Viabilidade agroeconômica do cultivo consorciado de coentro, alface e rúcula sob diferentes arranjos espaciais. *Enciclopédia Biosfera*, *10*(18), 3060-3069. DOI: https://conhecer.org.br/ojs/index.php/biosfera/article/view/2907

Medeiros, M. L. S., Demartelaere, A. C. F., Lima, J. S. S., Silva, M. L., & Pádua, G. V. G. (2019). Consorciação de caupi-hortaliça e beterraba sob diferentes quantidades de flor-de-seda incorporadas ao solo. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, *14*(1), 12-20. DOI: https://doi.org/10.18378/rvads.v14i1.6001

Mello, J. C. C. B. S., & Gomes, E. G. (2013). Eficiências aeroportuárias: uma abordagem comparativa com análise de envoltória de dados. *Revista de Economia e Administração*, *3*(1), 15-23. DOI: http://www.spell.org.br/documentos/ ver/ 25652

Morais, E. C., Lima, J. S. S., Bezerra Neto, F., Silva, J. N., Nunes, R. L. C., & Linhares, P. C. A. (2018). Habilidade competitiva e biológica do consórcio beterraba com caupi-hortaliça proveniente de adubação verde e de arranjos espaciais. *Revista Ceres*, *65*(5), 433-442. DOI: https://doi.org/10.1590/0034-737X201865050008

Nunes, R. L. C., Bezerra Neto, F., Lima, J. S. S., Barros Júnior, A. P., Chaves, A. P., & Silva, J. N. (2018). Agro-economic responsiveness of radish associations with cowpea in the presence of different amounts of *Calotropis procera*, spatial arrangements and agricultural crops. *Ciência e Agrotecnologia*, *42*(4), 350-363. DOI: https://doi.org/10.1590/1413-70542018424010318

Oliveira, L. A. A., Bezerra Neto, F., Silva, M. L., Oliveira, O. F. N., Lima, J. S. S., & Barros Júnior, A. P. (2015). Viabilidade agronômica de policultivos de rúcula/cenoura/alface sob quantidades de flor-de-seda e densidades populacionais. *Revista Caatinga*, *28*(4), 116-126. DOI: https://doi.org/10.1590/1983-21252015v28n413rc

Oliveira, A. P., Silva, J. A., Alves, A. U., Dorneles, C. S. M., Alves, A. U., Oliveira, A. N. P., ... Cruz, I. S. (2007). Rendimento de feijão-vagem em função de doses de K_2O. *Horticultura Brasileira*, *25*(1), 29-33, DOI: https://doi.org/10.1590/S0102-05362007000100007

Passos, F. D. A, Nunes, J., Boiago, N. P., Zanatta, F. S., Correa Junior, E. O., Araújo, L. R. V., ... Lima, G. B. (2019). Produtividade de milho em diferentes populações de plantio. *Revista Cultivando o Saber* (ed. esp.), 1-11. DOI: Retrieved from https://cultivandosaber.fag.edu.br/index.php/cultivando/article/view/976/897

Pinto, C. M., Pinto, O. R. O., & Pitombeira, J. B. (2012). Mamona e girassol no sistema de consorciação em arranjo de fileiras: habilidade competitiva. *Revista Brasileira de Agropecuária Sustentável*, *2*(2), 103-113 DOI: https://doi.org/10.21206/rbas.v2i1.57

Ribeiro, J. R. S., Bezerra Neto, F., Lima, J. S. S., Chaves, A. P., Silva, J. N., Santos, E. C., & Nunes, R. L. C. (2020). Production efficiency in cultivar combinations of beet and cowpea. *Horticultura Brasileira*, *38*(4), 445-453. DOI: https://doi.org/10.1590/s0102-0536202004017

Ribeiro, G. M., Bezerra Neto, F., Lima, J. S. S., Silva, M. L., Barros Júnior, A. P., & Santos, E. C. (2017). Agro-economic efficiency of the intercropping of carrot x cowpea-vegetable under different spatial arrangements and population densities. *Revista Caatinga*, *30*(4), 847-854. DOI: https://doi.org/10.1590/198321252017v30n404rc

Rêgo, L. G. S., Martins, C. M., Silva, E. F., Silva, J. J. A., & Lima, R. N. S. (2016). Pedogenesis and soil classification of an experimental farm in Mossoró, state of Rio Grande do Norte, Brazil. *Revista Caatinga*, *29*(4), 1036-1042. DOI: https://doi.org/10.1590/1983-21252016v29n430rc

Sediyama, M. A. N., Santos, I. C., & Lima, P. C. (2014). Cultivo de hortaliças no sistema orgânico. *Revista Ceres*, *61*(7), 829-837. DOI: https://doi.org/10.1590/0034-737x201461000008

Sugasti, J. B., Junqueira, A. M. R., & Saboya, P. A. (2013). Consórcio de rabanete, alface e quiabo e seu efeito sobre as características agronômicas das culturas, produção e índice de equivalência de área. *Revista Brasileira de Agroecologia*, *8*(2), 214-225.