Ciências Agrárias
SEMINA

DOI: 10.5433/1679-0359.2021v42n3Supl1p1453

Agro-economic efficiency dynamics in vegetable cowpea and radish cultivar combinations in strip-intercropping systems

Dinâmica de eficiência agroeconômica em combinações de cultivares de feijão-caupi e rabanete em sistemas consorciados em faixas

Iara Beatriz Silva Azevedo[1]; Francisco Bezerra Neto[2]; Jailma Suerda Silva de Lima[2]; Renato Leandro Costa Nunes[3]*; Elizangela Cabral dos Santos[2]; Aridênia Peixoto Chaves[1]; Josimar Nogueora da Silva[1]

Highlights

Cultivar combinations in cowpea-radish strip-intercrop lead to agroeconomic value.
Hsu test is a tool to select top cultivar combination in cowpea-radish intercrop.
LER, AYL, LUE and Z express complementarity and viability in cultivar combinations.

Abstract

This work aimed to evaluate the dynamics of agro-economic efficiency in combinations of vegetable cowpea and radish cultivars in strip-intercropping systems through agronomic, economic and competition indices tested by the Hsu test in a semi-arid environment. The experimental design was a completely randomised block with eight treatments and four replications. The treatments consisted of combinations of four cowpea cultivars, BRS Tumucumaque, BRS Cauamé, BRS Guariba, and BRS Itaim, with two radish cultivars, Crimson Gigante and Zapp. In each block, individual plots of these cultivars in single cultivation were planted as additional treatments to obtain the system indices. The indices of agronomic and economic efficiency and of competition evaluated were land equivalent ratio (LER), actual yield loss (AYL), land use efficiency (LUE%), score of the canonical variable (Z), gross income (GI), net income (NI), rate of return (RR), corrected monetary advantage (CMA), competitive ratio (CR) and the aggressivity of radish over cowpea (Ar) and cowpea over radish (Avc). The cowpea cultivar BRS Tumucumaque, when combined with the radish cultivar Zapp, provided the highest agro-economic efficiency of the intercropped system in a semi-arid environment. The

[1] Graduate Students of the Plant Science Graduate Program, Rural Federal University for Semi-Arid, UFERSA, Mossoró, RN, Brazil. E-mail: iaraazevedo15@hotmail.com; aridenia.peixoto@hotmail.com; josimar2160@hotmail.com
[2] Profs. PhD, Agronomic and Forestry Sciences Department, UFERSA, Mossoró, RN, Brazil. E-mail: bezerra@ufersa.edu.br; jailma@ufersa.edu.br; elizangelacabral@ufersa.edu.br
[3] Prof., Education Department, Federal Institute of Ceará, IFCE, Campus of Limoeiro do Norte, Ceará, Brazil. E-mail: renatoleandro.ce@hotmail.com
* Author for correspondence

Received: Aug. 11, 2020 - Approved: Feb. 09, 2021

complementarity and sustainability of the intercropping systems of cowpea and radish were observed in the results of the Hsu test applied to the indices of agro-economic efficiency and of competition. Radish was the dominant crop.
Key words: *Vigna unguiculata. Raphanus sativus.* Crop association. Complementarity and sustainability.

Resumo

Este trabalho teve como objetivo avaliar a dinâmica de eficiência agroeconômica de combinações de cultivares de caupi-hortaliça e de rabanete em consórcio através de índices agronômicos, econômicos e de competição testados pelo teste de Hsu em ambiente semiárido. O delineamento experimental foi o de blocos casualizados completos, com oito tratamentos e quatro repetições. Os tratamentos consistiram de combinações de quatro cultivares de caupi-hortaliça, BRS Tumucumaque, BRS Cauamé, BRS Guariba e BRS Itaim, com duas cultivares de rabanete, Crimson Gigante e Zapp. Em cada bloco, parcelas individuais dessas cultivares em monocultivo foram plantadas como tratamentos adicionais para obtenção dos índices do sistema. Os índices de eficiência agronômica, econômica e de competição avaliados foram: relação equivalente da terra (RET), perda real de rendimento (PRR), indice de eficiencia de uso da terra (EUT), escore da variável canônica (Z), renda bruta (RB), renda líquida (RL), taxa de retorno (TR), vantagem monetária corrigida (VMC), taxa de competição (TC) e o índice de superação do rabanete sobre o caupi-hortaliça (ISr) e do caupi-hortaliça sobre rabanete (ISch). A cultivar de caupi-hortaliça BRS Tumucumaque quando combinada com a cultivar de rabanete Zapp proporcionou a maior eficiência agroeconômica do sistema consorciado em ambiente semiárido. A complementaridade e a sustentabilidade dos sistemas consorciados de caupi e rabanete foram registradas nos resultados do teste de Hsu aplicado aos indices de eficiência agroeconômica e de competição. O rabanete foi à cultura dominante.
Palavras-chave: *Vigna unguiculata. Raphanus sativus.* Consorciação de culturas. Complementaridade e sustentabilidade.

Introduction

With the emergence of new commercial cultivars of the vegetable crops radish and cowpea, adapted to the semi-arid climate of northeast Brazil, it is important to seek information and obtain data on their behaviour and performance in intercropped agrosystems. Therefore, studying the interspecific combination of these materials is of paramount importance for obtaining high production and high agro-economic efficiency in vegetable intercropping systems.

In semi-arid regions, intercropping is an efficient measure to increase crop production (Bezerra & Robichaux, 1997), maximise the use of the environmental resources and reduce labor (Negreiros, Bezerra, Porto, & Santos, 2002).

For the success of this practice, it is important that the companion cultures show complementary. This is possible when the species have different ecological niches, thus maximising light use as well as water and nutrient absorption. The efficiency of intercropped systems depends on this maximization between cultures and the period of greatest demand for environmental resources. When this demand is not coincident, competition between cultures can be minimised and, thus, constitutes a determining factor in the efficiency of the intercropping system (Willey, 1979).

In addition, the choice of suitable cultivars for certain edaphoclimatic conditions is essential to increase the system's production and productivity. Intercropping has been little studied in relation to the selection of cultivar combinations suitable for this cultivation system, and most studies focused on the selection of cultivars for monoculture systems, making it difficult to understand the behaviour of these genotypes in the association system (Costa et al., 2017). Thus, the main challenge is to know which of these materials can produce well in intercropping and offer good quality products.

For the quantification and evaluation of intercropping systems, several indices that express the agro-economic efficiency of the systems' viability have been developed. To quantify agronomic-biological efficiency, the following indices have been proposed: land equivalent ratio (LER), actual yield loss and score of the canonical variable. In terms of the economic efficiency evaluation, the indicators gross and net income (GI, NI), rate of return and profit margin have been used (Cecílio et al., 2015). To express competitiveness, the relative crowding coefficient and aggressivity indices of both cultures have been applied.

A few attempts have been made to evaluate cultivar combinations of vegetable crops in intercropping. For example, Lima et al. (2010), evaluating the performance of arugula cultivars in two systems intercropped with carrot cultivars, recorded LER, GI and NI values of 1.45, 79,887.40 and 63,420.03 R\$ ha^{-1}, respectively, with the combination of the 'Brasília' carrot cultivar and the arugula cultivar 'Cultivada'. Costa et al. (2017), evaluating combinations of vegetable cowpea cultivars with carrot cultivars in strip-intercropping, obtained LER and Z values of 1.65 and 1.01, respectively, and GI, NI, RR and MMA values of 27,129.37, 13,277.75, 1.96 and 5,477.58 R\$ ha^{-1}, respectively, for the combination of the vegetable cowpea cultivar BRS Guariba and the carrot cultivar Alvorada.

In view of the scarcity of information on combinations of vegetable cowpea and radish cultivars in intercropping systems, we evaluated the agro-economic efficiency of combinations of vegetable cowpea and radish cultivars in intercropping by the Hsu test in a semi-arid environment.

Materials and Methods

Experiments were conducted in the periods from August to October 2016 and from October to December 2017 in different areas of the Experimental Rafael Fernandes Farm, located in the Lagoinha district (5° 03'37 "S and 37° 23'50" W Gr), municipality of Mossoró, RN, in soils classified as typical dystrophic red Argisol. Table 1 shows the results of analyses of samples taken from these soils in the 0 to 20-cm layer.

Table 1
Chemical analyses of the soil before the incorporation of *C. procera* biomass in the cropping years 2016 and 2017 in Lagoinha (RN)

Before the incorporation of *C. procera* biomass													
Cropping year	N g/kg	pH (water)	CE ds/m	M.O g/kg	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cu	Fe	Mn	Zn
					mg/dm³			cmolc/dm³		mg/dm³			
2016	0.51	7.30	1.86	3.10	25.7	45.1	15.0	2.41	0.72	0.08	2.37	9.64	6.59
2017	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 climate of the region is semi-arid and, according to Köppen, classified as 'BShw', dry and very hot, with rain from summer to autumn. Average annual temperature is 27.4ºC, with a relative humidity of 68.9% and an average annual precipitation of 673.9 mm (Alvares et al., 2014). Figure 1 shows the maximum and minimum temperatures and the relative humidity of each cropping year.

We used a completely randomised block design with eight treatments and four replications. The treatments consisted of the combinations of four vegetable cowpea cultivars (BRS Tumucumaque, BRS Cauamé, BRS Guariba and BRS Itaim) with two radish cultivars (Crimson Gigante and Zapp). These materials are recommended for monocropping cultivation in semi-arid conditions in northeastern Brazil. The first three vegetable cowpea cultivars have a semi-erect stature and an indeterminate growth habit, whereas the latter one has an erect stature and a determined growth habit. All cowpea cultivars have a crop cycle between 65 and 70 days. The Crimson Gigante radish cultivar has characterised by a great height and a crop cycle between 30 and 35 days, whereas the Zapp cultivar has a medium size and a crop cycle between 25 and 30 days. In each block, individual plots of these cultivars were planted as additional treatments to obtain the agronomic-biological and economic efficiency indices as well as the competition indices.

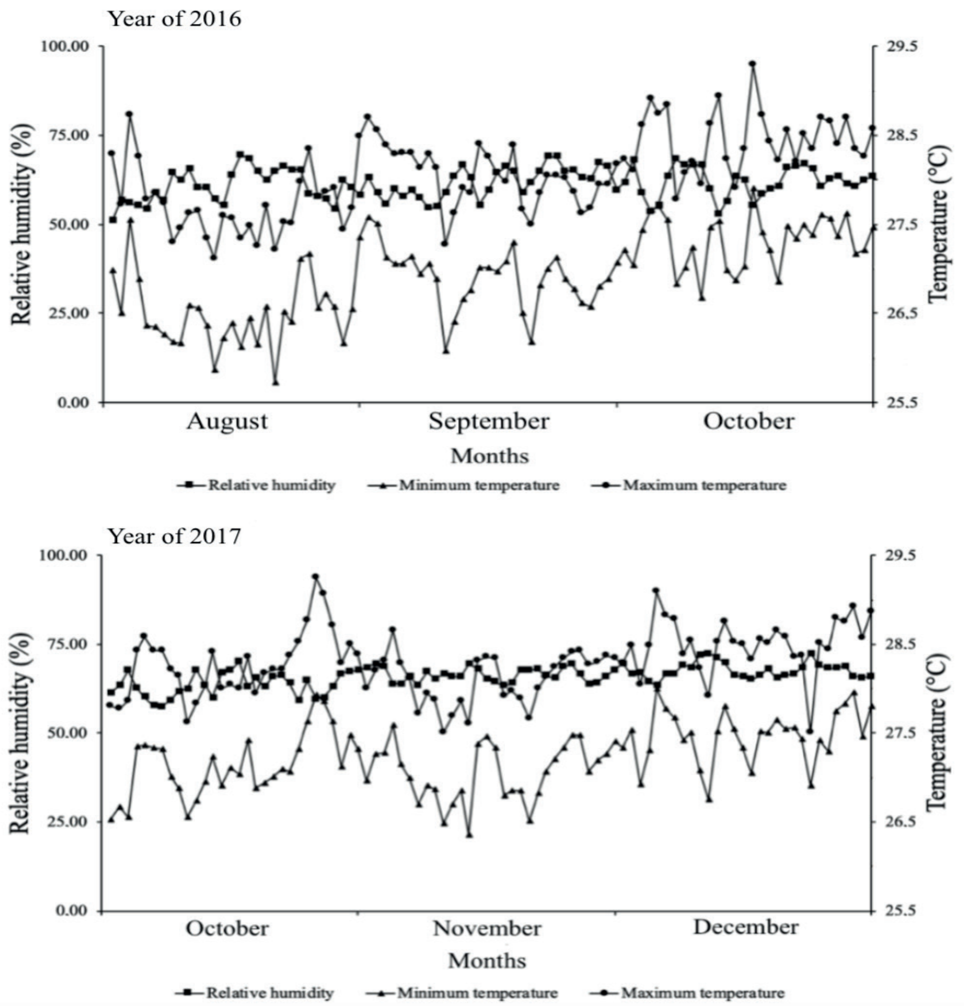

Figure 1. Climatic data, provided by the National Institute of Meteorology, for the cropping years 2016 and 2017, Lagoinha (RN).

The association of these cultivars in combinations was established in alternating strips of the component crops in the proportion of 50% of the area for vegetable cowpea and 50% of the area for radish, with each plot consisting of a strip of four rows of cowpea alternated with a strip of four rows of radish, flanked by two radish border rows on one side and two rows of vegetable cowpea on the other side, constituting the side borders. The total area of each experimental plot in the intercropped cultivation was 3.60 m^2 (3.00 x 1.20 m), containing 12 rows of plants, with a harvest area of 2.00 m^2 (2.00 x 1.00 m), containing eight rows of plants, four with cowpea and four with radish (Figure 2). The spacing of vegetable cowpea was 0.25 x 0.10 m, with 40 plants per harvest area, and the radish spacing was 0.25 x 0.04 m, with 100 plants per harvest area, resulting in a population of 200,000 and 500,000 plants per hectare, respectively.

In the single cropping of vegetable cowpea cultivars, the experimental plots had a total area of 3.60 m² (3.00 x 1.20 m), containing six rows of plants, and a harvest area of 2.00 m², formed by the four central rows of plants in the 0.50 x 0.10-m spacing with 40 plants per harvest area. The experimental plots of radish had a total area of 1.44 m² (1.20 x 1.20 m), containing six rows of plants and a harvest area of 0.80 m² (0.80 x 1.00 m), formed by the four central rows of plants at a spacing of 0.20 x 0.10 m, with 40 plants per harvest area. Population densities of cowpea and radish were the same in both cropping systems.

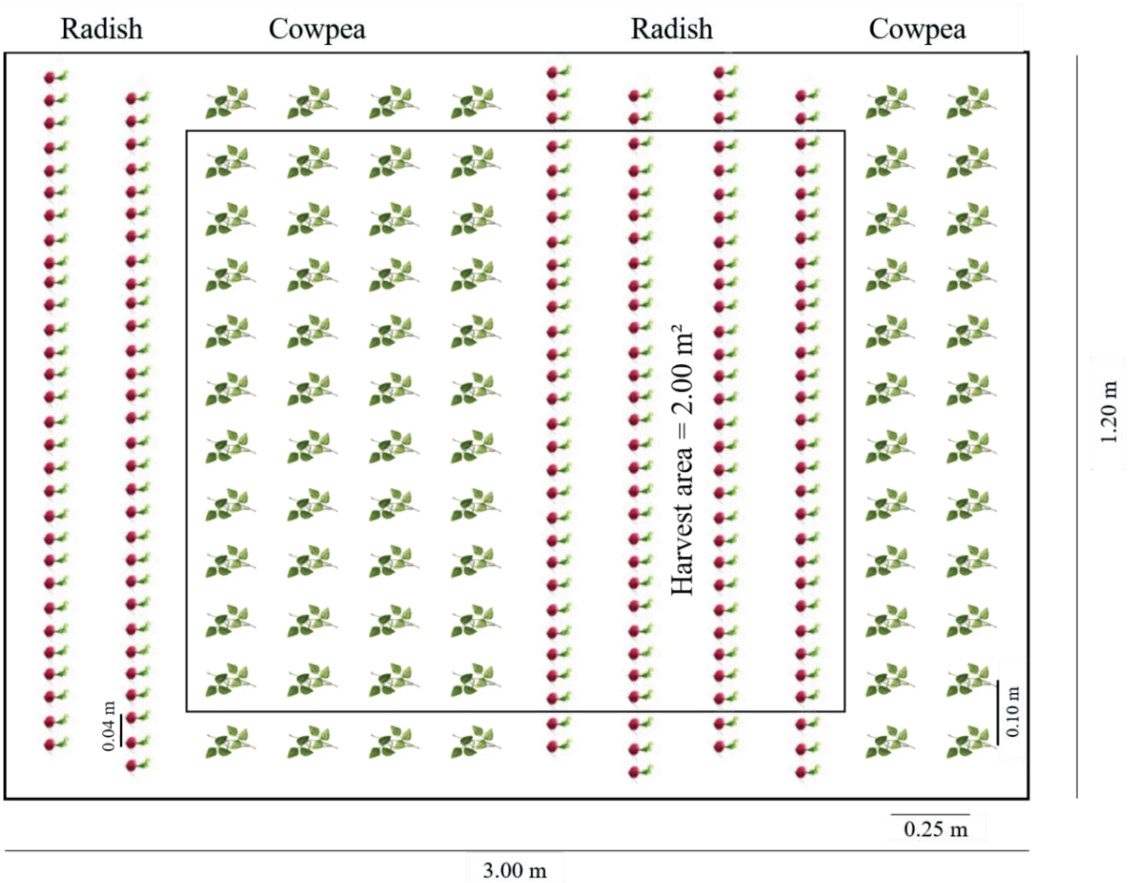

Figure 2. Detail of an experimental plot with the combination of a cowpea ( ) cultivar with a radish ( ) cultivar in a strip intercropping system, where each crop occupied 50% of the planting area.

Fertilisation was carried out with 49.86 t ha⁻¹ of *C. procera* incorporated in the soil in the plots of the intercropped cultivation, according to the recommendations of trials carried out in the region previously. In the plots of single crops of vegetable cowpea and radish, fertilisation was performed with 59.40 and 44.00 t ha^{-1} of *C. procera* incorporated into the soil, respectively, based on previously conducted trials. In samples of this green manure, the contents of macro- and micronutrients in the dry matter were determined (Table 2).

Table 2
Macronutrient contents of C. procera in the cropping years 2016 and 2017 in the experimental areas

Cropping year	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	
2016	18.40	3.10	14.50	16.30	13.50	100.50	21.75	37.88	3.85	608.5	25:1
2017	15.30	0.66	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 - Iron; Mn - Manganese; Zn - Zinc; Cu - Copper; Na - Sodium and C/N - Carbon/nitrogen ratio.

Sowing, treatment and harvesting were carried out manually. Irrigation was carried out using the micro-sprinkler system in two shifts (morning and afternoon), with an 8-mm water depth.

The productivities of vegetable cowpea and radish were recorded, and the indices of agronomic-biological efficiency, economic efficiency and competition were determined.

The agronomic-biological efficiency indices evaluated in the tested intercropping systems were as follows: land equivalent ratio (LER), defined by the following expression: $LER = LER_{vc} + LER_{r} = (Y_{vcr}/Y_{vcm}) + (Y_{rvc}/Y_{rm})$, where LER_{vc} and LER_{r} represent the partial LERs of intercropping system, Y_{vcr} corresponds to the vegetable cowpea productivity in intercropping with the radish, the Y_{vcm} represents the productivity of the vegetable cowpea in monoculture, Y_{rvc} is the productivity of the radish in intercropping with the vegetable cowpea and Y_{rm} is the productivity of the radish in monoculture. When LER > 1, intercropping favours the growth and yield of component crops, and when LER < 1, intercropping negatively affects crop growth and yield (Xu, Li, & Shan, 2008).

Land use efficiency (LUE %) is an agronomic/biological index obtained from the mean between land equivalent ratio (LER) and area time equivalency ratio (ATER) and expressed in percentage (Gendy, Nosir, & Nawar, 2017). It was calculated through the following expression: $LUE\% = [(LER + ATER)/2] \times 100$. The area time equivalency ratio is an index proposed by Hiebsch & McCollum (1987) that provides a more realistic comparison of the yield advantage of intercropping over mono-cropping in terms of the time taken by component crops in the intercropping systems. It can be calculated by the following formula: $ATER = (LER_{vc}\ t_{vc} + LER_{r}\ t_{r}) \times T$, where LER_{vc} and LER_{r} represent the partial LERs of the intercropping system (previously defined), t_{vc} and t_{r} are the duration of crop *vc* and *r*, T is the duration of the whole intercropping period.

Actual yield loss (AYL) represents the proportionate yield loss or gain of intercrops in comparison to the respective sole crop; it takes into account the actual sown proportion of the component crops with its pure stand and was calculated following the proposed expression by Banik (1996): $AYL = AYL_{vc} + AYL_{r}$, where AYL_{vc} and AYL_{r} are partial AYLs of the component crops *vc* and *r*. These partial AYLs have the following expressions: $AYL_{vc} = [LER_{vc} \times (100/Z_{vcr}) - 1]$ for crop vc and $AYL_{r} = [LER_{r} \times (100/Z_{rvc}) - 1]$ for crop *r*, where LER_{vc} and LER_{r} represent the partial LERs of the intercropping system,

Z_{vcr} represents the sown proportion (50% of the sown area) of intercrop vc (vegetable cowpea) in combination with r (radish) and Z_{rvc} the sown proportion (50% of the sown area) of intercrop *r* (radish) in combination with *vc* (Figure 2). If $AYL_{rvc} > 0$, there is an accumulated advantage of the intercropping in relation to monoculture; $AYL_{rvc} < 0$ indicates a disadvantage of the intercropping system.

The score of the canonical variable (Z) was obtained through bivariate analysis of variance of vegetable cowpea and radish productivities. This analysis allows to examine the patterns of crop variation at the same time and, thus, can be used as a standard procedure for interpreting the data of the intercropped systems.

The economic indices evaluated in the intercropped systems from the tested cultivar combinations were as follows: 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 price paid to the producer for the vegetable cowpea in 2016 and 2017 was R$ 6.50 and R$ 7.00 per kilogram, respectively, and for radish, it was R$ 2.90 and R$ 3.00 per kilogram, respectively.

Net income (NI) was obtained through the difference between the gross income (GI) per hectare and the total costs (TC) involved in obtaining the intercropped systems.

The rate of return (RR) was expressed by the ratio between gross income (GI) and total costs (TC), that is, RR = GI/TC, corresponding to how many reals are obtained for each real invested in the intercropping of vegetable cowpea and radish.

The corrected monetary advantage was determined by the following expression (Bezerra et al., 2010): CMA = NI * (LER -1)/LER. Higher MMAs and NIs indicate more profitable intercropping systems.

The competition indices evaluated in the intercropped systems from the tested cultivar combinations were as follows: competitive ratio (CR) and crop aggressivity indices (A). The CR was obtained with the formula suggested by Willey & Rao (1980): $CR = [(LER_{vc}/LER_{r}) \times (Z_{rvc}/Z_{vcr})] + [(LER_{r}/LER_{vc}) \times (Z_{vcr}/Z_{rvc})]$, where LER_{vc} and LER_{r} were obtained from the LER and Z_{vcr} is the sown proportion of vegetable cowpea in intercropping with radish; Z_{rvc} is the sown proportion of radish in intercropping with vegetable cowpea. The CR evaluates the competition between different intercropping systems and provides a better measure of competitive ability of the component crops. Systems with higher CR values make better use of the environmental resources.

Aggressivity (A) indicates how much the relative increase in the yield of a component crop is greater than that of the other crop in an intercropping system, that is, it is an index to measure the dominance of a crop in relation to the other. This index was proposed by McGilchrist & Trenbath (1971). The aggressivity of radish over cowpea (A_{rvc}) and the aggressivity of cowpea over radish (A_{vcr}) were determined by the following expressions: $A_{rvc} = (Y_{rvc}/Y_{rm} * Z_{rvc}) - (Y_{vcr}/Y_{vcm} * Z_{vcr})$ and $A_{vcr} = (Y_{vcr}/Y_{vcm} * Z_{vcr}) - (Y_{rvc}/Y_{rm} * Z_{rvc})$. When A is positive, the culture with a positive sign is dominant and that with a negative sign is dominated.

The index data were submitted to joint analysis of variance over the years of cultivation, using the SISVAR program (Ferreira, 2011). The Bartlett test was used to verify the homogeneity of the variances of each index between the cropping years; these variances were homogeneous. The mean differences of the cultivar combinations were separated and tested by the Hsu test at a 5% significance level.

The test proposed by Hsu (1981) compares all treatments with the best one. Thus, if a greater treatment effect is the best, even if the best treatment is unknown, we can define the parameters of preliminary interest as follows: $\max_{j=1,\ldots,k} \mu_j - \mu_i, i = 1,\ldots,k.$ (1), representing the difference between the effect of the best treatment and each one of the treatment's k-effects. If the greatest effect of the treatment implies a better treatment, then the parameters $\mu_i - \max_{j \neq i} \mu_j, i = 1,\ldots,k$, contain all the information of 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 as follows: $\mu_i - \min_{j \neq i} \mu_j, i = 1,\ldots,k$.

If the best treatment is the highest average between factor levels, according to Hsu, a set of intervals with a confidence level of (1-α) 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 calculation of the limits of these intervals is performed using the following equations:

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

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

where $d_\alpha(k, N-k)$ represents a tabulated value (Hsu Table) that depends on the number of levels (k) and the number of degrees of freedom of errors (N–k)) and ni is the number of replicates of level i (for unbalanced data). For balanced data, all ni 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,

$$\left[D_i^-\right]^- = \min\{0, D_i^-\} = \begin{cases} D_i^- \text{ if } x < 0 \\ 0 \text{ otherwise} \end{cases} \quad \text{and}$$

$$\left[D_i^+\right]^- = \max\{0, D_i^+\} = \begin{cases} D_i^- \text{ if } x > 0 \\ 0 \text{ otherwise.} \end{cases} \quad .$$

A procedure for identifying the best combination of cultivars, in a set of simultaneous confidence intervals for paired comparisons between the best mean (of highest value) and of each treatment mean, was carried out using the software Action (Equipe Estatcamp, 2014).

Results and Discussion

Agronomic-biological efficiency indices

No significant interaction was observed between combinations of vegetable cowpea and radish cultivars and cropping years in the agronomic-biological efficiency indices. However, significant differences between the cropping years and cultivar combinations of the cultures were recorded (Table 3). The year 2017 provided the highest values for these indices, and this was due to the better weather conditions, resulting in better growth and development and, consequently, greater yields (Figure 1).

Table 3

F values and mean values for land equivalent ratio (LER), actual yield loss (AYL), land use efficiency (LUE) and score of the canonical variable (Z) from the combinations of vegetable cowpea and radish cultivars

Sources of variation	DF	LER	AYL	LUE (%)	Z
Blocks (Cropping years)	6	0.75 ns	0.74 ns	0.75 ns	3.69 **
Cropping years (Y)	1	275.77**	279.81**	265.82**	381.72**
Cultivar combinations (C)	7	2.54*	2.32*	2.77*	2.43*
Y x C	7	1.34 ns	1.46 ns	1.48 ns	2.01 ns
Cropping year					
2016		1.17b †	0.30b	159.16b	- 0.05b
2017		3.12a	4.25a	402.90a	0.69a
CV (%)		21.98	21.43	21.28	27.86

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

Regarding the cultivar combinations, the values of the means, of the differences between the means of the i-th combination and the maximum value between the means of the other combinations and the simultaneous confidence intervals of these differences for the land equivalent ratio (LER), actual yield loss (AYL), land use efficiency (LUE) and canonical variable score (Z) from combinations of vegetable cowpea and radish cultivars are shown in Table 4.

Ciências Agrárias
SEMINA

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 land equivalent ratio (LER), actual yield loss (AYL), land use efficiency (LUE) and score of the canonical variable (Z) from the combinations of vegetable cowpea and radish cultivars

Cultivar combinations		LER			AYL		
		$\overline{Y}$	D	SCI	$\overline{Y}$	D	SCI
BRS Tumucumaque	C. Gigante	2.45	-0.14	-1.59 to 1.31	2.89	-0.06	-3.00 to 2.89
BRS Tumucumaque	Zapp	2.55	0.14	-1.31 to 1.59	2.99	0.06	-2.89 to 3.00
BRS Cauamé	C. Gigante	2.12	-0.45	-1.90 to 1.00	2.24	-0.68	-3.62 to 2.26
BRS Cauamé	Zapp	1.96	-0.67	-2.12 to 0.78	1.92	-1.12	-4.06 to 1.82
BRS Guariba	C. Gigante	2.13	-0.48	-1.93 to 0.97	2.25	-0.74	-3.68 to 2.20
BRS Guariba	Zapp	2.24	-0.35	-1.80 to 1.10	2.48	-0.47	-3.42 to 2.47
BRS Itaim	C. Gigante	1.73	-0.95	-2.40 to 0.50	1.46	-1.67	-4.61 to 1.28
BRS Itaim	Zapp	2.00	-0.68	-2.13 to 0.77	1.99	-1.13	-4.07 to 1.81
		LUE (%)			Z		
		$\overline{Y}$	D	SCI	$\overline{Y}$	D	SCI
BRS Tumucumaque	C. Gigante	324	-12.00	-194.9 to 170.9	0.32	-0.09	-0.61 to 0.43
BRS Tumucumaque	Zapp	334	12.00	-170.9 to 194.9	0.14	0.02	0.50 to 0.54
BRS Cauamé	C. Gigante	275	-58.54	-241.4 to 124.4	0.37	-0.04	-0.56 to 0.49
BRS Cauamé	Zapp	258	-85.31	-268.2 to 97.6	0.28	-0.12	-0.65 to 0.40
BRS Guariba	C. Gigante	279	-61.00	-243.9 to 121.9	0.38	-0.02	-0.54 to 0.50
BRS Guariba	Zapp	292	-43.82	-226.7 to 139.1	0.32	-0.08	-0.61 to 0.44
BRS Itaim	C. Gigante	228	-121.39	-304.3 to 61.5	0.31	-0.09	-0.62 to 0.44
BRS Itaim	Zapp	259	-89.47	-272.4 to 93.4	0.41	-0.27	-0.79 to 0.25

The highest mean values of LER, LUE and AYL were found for the combination of cultivar BRS Tumucumaque with cultivar Zapp. The LER of 2.55 and LUE of 334% indicate that this cultivar combination had the highest biological efficiency of the intercrops in terms of using environmental resources compared to the single cultivation of these cultivars. Likewise, the highest average value of AYL (2.99) was obtained for this combination, indicating the accumulated advantage of intercropping in relation to the monocropping of these cultivars. On the other hand, the lowest Z value (0.14) was obtained in this same combination of cultivars, indicating that the patterns of competition variation between cultivars at the same time were not as strong when compared to the other combinations, leading to a more efficient combination in the management of available environmental resources (Table 4).

The confidence interval regarding the combination of BRS Tumucumaque and Zapp cultivars had a large part of the positive values in the LER, LUE, AYL and Z indices, expressed by the positive value of the difference between the mean of the i-th combination and the maximum value between the averages of the other combinations, leading us to infer that this combination is the best among the others evaluated by the Hsu test.

Therefore, the intercropping that showed the greatest advantage in agronomic efficiency was the one where the cowpea cultivar BRS Tumucumaque was combined with the radish cultivar Zapp. This result in relation to the cowpea cultivars tested diverged from that obtained by Costa et al. (2017), who evaluated the combinations of the same cowpea cultivars tested in this research with the carrot cultivars in strip-intercropping and obtained a greater agronomic advantage with the combination of the cowpea cultivar BRS Guariba and the carrot cultivar Alvorada. These results may be related to the morphological characteristics of the cultivars in combination, among them, the stature of the plants; vegetable cowpea cultivars were higher than radish plants. Both crops have large trifoliate leaves with a cylindrical shape for cowpea and an oval shape for radish, with a high light use efficiency. The root system of the cowpea was deeper than that of the radish, which was more superficial, resulting in a more efficient use of space. Another relevant factor that can influence the competence on the part of the system is the cowpea's ability to fix atmospheric nitrogen, thereby improving soil fertility. According to Chen et al. (2017), in the absence of nitrogen fertilisers, the reduced intake of N decreases the demand for nitrogen fertilisers in the intercropping systems.

Thus, the combination BRS Tumucumaque with Zapp showed better results of companionship, with a greater affinity for the use of environmental resources. According to Costa et al. (2017), the best combinations between species in intercropping are those where there is a high complementarity between cultivars (high overall effect of the intercropping). According to Iqbal et al. (2019), the efficient use of resources is essential to obtain the best yield from the crop.

Economic indices

No significant interaction was observed between combinations of vegetable cowpea and radish cultivars and cropping years in the economic efficiency indices. However, significant differences between the cropping years and cultivar combinations of the cultures were recorded (Table 5). In 2017, the highest values for these indices were observed, most likely because of the more favourable weather conditions compared to 2016.

Table 5
F values for gross income (GI), net income (NI), rate of return (RR) and corrected monetary advantage (CMA) from the combinations of vegetable cowpea and radish cultivars

Sources of variation	DF	GI (R$ t ha^{-1})	NI (R$ t ha^{-1})	RR	CMA (R$ t ha^{-1})
Blocks (Cropping years)	6	0.95 ^{ns}	0.95 ^{ns}	0.94 ^{ns}	0.71^{ns}
Cropping years (Y)	1	352.69**	353.69**	350.82**	242.81**
Cultivar combinations (C)	7	2.32*	2.36*	2.52*	2.45*
Y x C	7	1.81 ^{ns}	1.85 ^{ns}	1.94 ^{ns}	1.48 ^{ns}
Cropping year					
2016		16,492.14b	5,321.42b	1.47b	1,014.89b †
2017		44,948.08a	33,777.37a	4.02a	23,067.56a
CV (%)		19.73	28.25	19.81	27.70

** = P < 0.01; * = P < 0.05; ns = P > 0.05. † Means followed by different lowercase letters in the column differ from each other by the F test at the 5% probability level.

Regarding the cultivar combinations, the values of the means, of the differences between the means of the i-th combination and the maximum value between the averages of the other combinations and of the simultaneous confidence intervals of these differences for the economic efficiency indices of the intercropping systems of cowpea vegetable and radish, obtained from the cultivar combinations of these two crops and expressed by gross and net incomes rate of return and corrected monetary advantage (GI, NI, RR and CMA), are shown in Table 6. In general, in all tested combinations, there was a financial return of the studied intercropping systems, expressed by the values of the economic indicators evaluated. This leads us to infer that the intercropping of vegetable cowpea and radish is economically viable in a semi-arid environment.

Table 6

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 gross income (GI), net income (NI), rate of return (RR) and corrected monetary advantage (CMA) from the combinations of vegetable cowpea and radish cultivars

Cultivar combinations		GI			NI		
		$\overline{Y}$	D	SCI	$\overline{Y}$	D	SCI
BRS Tumucumaque	C. Gigante	34,165.93	-126.85	-20,308.13 to 20,054.44	23,647.72	-421.84	-20,603.12 to 19,759.45
BRS Tumucumaque	Zapp	34,368.31	126.85	-20,054.44 to 20,308.13	23,345.09	421.84	-19,759.45 to 20,603.12
BRS Cauamé	C. Gigante	31,333.78	-3,395.40	-23,576.68 to 16,785.89	20,015.58	-3,690.39	-23,871.67 to 16,490.90
BRS Cauamé	Zapp	28,194.67	-6,416.67	-26,597.95 to 13,764.62	17,171.45	-6,416.67	-26,597.95 to 13,764.62
BRS Guariba	C. Gigante	29,959.90	-4,816.49	-24,997.78 to 15,364.79	18,641.69	-5,111.48	-25,292.77 to 15,069.80
BRS Guariba	Zapp	31,736.83	-2,631.48	-22,812.77 to 17,549.80	20,713.61	-2,631.48	-22,812.77 to 17,549.80
BRS Itaim	C. Gigante	25,713.52	-9,413.59	-29,594.88 to 10,767.69	14,395.31	-9,708.58	-29,889.87 to 10,472.70
BRS Itaim	Zapp	29,487.94	-5,067.42	-25,248.70 to 15,113.87	18,464.73	-5,067.42	-25,248.70 to 15,113.87
		RR			CMA		
		$\overline{Y}$	D	SCI	$\overline{Y}$	D	SCI
BRS Tumucumaque	C. Gigante	3.09	-0.09	-1.90 to 1.72	15,000.76	-1,253.83	-17,052.69 to 14,545.03
BRS Tumucumaque	Zapp	3.12	0.09	-1.72 to 1.90	16,047.04	1,253.83	-14,545.03 to 17,052.69
BRS Cauamé	C. Gigante	2.77	-0.38	-2.19 to 1.43	12,676.57	-3,339.11	-19,137.97 to 12,459.75
BRS Cauamé	Zapp	2.56	-0.58	-2.39 to 1.23	10,185.50	-5,820.48	-21,619.34 to 9,978.38
BRS Guariba	C. Gigante	2.65	-0.51	-2.32 to 1.30	10,549.18	-5,607.02	-21,405.88 to 10,191.84
BRS Guariba	Zapp	2.88	-0.24	-2.05 to 1.57	12,950.73	-3,216.28	-19,015.14 to 12,582.58
BRS Itaim	C. Gigante	2.27	-0.91	-2.72 to 0.90	7,586.53	-8,583.02	-24,381.88 to 7,215.83
BRS Itaim	Zapp	2.67	-0.46	-2.27 to 1.35	11,333.51	-4,969.42	-20,768.28 to 10,829.43

The combination with the highest average value, a positive difference between the means of the i-th combination and the maximum value between the means of the other combinations and the confidence interval with most of the positive values of the economic indices evaluated was that of the cowpea cultivar BRS Tumucumaque with the radish cultivar Zapp.

These results show that the agronomic efficiency achieved by combining the cultivar BRS Tumucumaque with the cultivar Zapp was translated in terms of economic efficiency, strongly suggesting that the association of cultivar BRS Tumucumaque with cultivar Zapp it also expressed as an economic superiority among the tested combinations.

It is important to note that part of this economic gain is due to the resulting interactions between the cultivar BRS Tumucumaque and the cultivar Zapp, converting into mutually beneficial effects, thus reducing the use of external inputs. Several studies have demonstrated the importance of intercropping systems with agronomic-biological, ecological and economic advantages (He et al., 2011; Kebebew, Belete, & Tana, 2014).

Costa et al. (2017), combining the same cowpea cultivars used in this research with two carrot cultivars in a semi-arid environment, obtained a gross income, net income, corrected monetary advantage and a rate of return of 27,129 13,277, 5,477 R$ ha^{-1} and 1.96, respectively, for the combination of the vegetable cowpea cultivar BRS Guariba with the carrot cultivar Alvorada, values lower than those obtained in this research with the same economic indices evaluated (34,368, 23,345, 16,047 R$ ha^{-1} and 3.12) with the combination of the cowpea cultivar BRS Tumucumaque and the radish cultivar Zapp. These differences can be explained by the type of tuberose used. In this research, we used radish, whereas Costa et al. (2017) used carrot, a far more aggressive crop in terms of competition than radish. Thus, there is an urgent need to optimise the combinations of cultivars in intercropping systems of vegetable cowpea and radish to obtain maximum productivity and economic return.

However, in the absence of adequate management of the production factors, such as combination of cultivars, spatial arrangement, plant density or fertilisation, yield gains cannot be obtained (Ghosh et al., 2010; Qasem, 2011). According to Himmelstein, Ares, Gallagher and Myers (2017), unwanted results in the intercropping system can be attributed to failures in the management of these production factors.

Competition indices

No significant interaction was observed between combinations of vegetable cowpea and radish cultivars and cropping years in the competition indices evaluated. However, significant differences between the cropping years and cultivar combinations were recorded in these indices (Table 7). In particular, A_r and CR showed higher indices in 2017 and A_{vc} in 2016.

Regarding the cultivar combinations, the values of the means, of the differences between the means of the i-th combination and the maximum value between the means of the other combinations and the simultaneous confidence intervals of these differences for the aggressivity indices and competitive ratio are shown in Table 8.

Table 7

F values for the competitive ratio (CR) from the combinations of vegetable cowpea and radish cultivars, of the aggressivity indices of the radish cultivars (A_r) over vegetable cowpea cultivars and of the vegetable cowpea cultivars (A_{vc}) over the radish cultivars

Sources of variation	DF	CR	Ar	Avc
Blocks (Cropping years)	6	1.48 ^{ns}	0.87 ^{ns}	0.87 **
Cropping years (Y)	1	42.70 **	200.34**	200.34**
Cultivar combinations (C)	7	2.50*	2.32*	2.32*
Y x C	7	0.64 ^{ns}	2.09 ^{ns}	2.09 ^{ns}
Cropping year				
2016		2.53b	0.21b	-0.21a †
2017		3.67a	3.45a	-3.45b
CV (%)		22.51	21.90	21.90

** = P < 0.01; * = P < 0.05; ns = P > 0.05. † Means followed by different lowercase letters in the column differ from each other by F test at the 5% probability level.

Table 8

Mean values ($\bar{Y}$), 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 aggressivity indices of the radish cultivars (A_r) over vegetable cowpea cultivars, as well as the vegetable cowpea cultivars (A_{vc}) over the radish cultivars and for the competitive ratio (CR)

Cultivar combinations		A_r			A_{vc}		
		$\bar{Y}$	D	SCI	$\bar{Y}$	D	SCI
BRS Tumucumaque	C. Gigante	1.60	-0.99	-3.35 to 1.38	-1.60	-0.20	-2.57 to 2.16
BRS Tumucumaque	Zapp	2.58	0.61	-1.76 to 2.97	-2.58	-1.19	-3.56 to 1.18
BRS Cauamé	C. Gigante	1.95	-0.63	-3.00 to 1.74	-1.95	-0.56	-2.92 to 1.81
BRS Cauamé	Zapp	1.57	-1.01	-3.38 to 1.36	-1.57	-0.18	-2.54 to 2.19
BRS Guariba	C. Gigante	1.94	-0.64	-3.01 to 1.73	-1.94	-0.55	-2.92 to 1.82
BRS Guariba	Zapp	1.97	-0.61	-2.97 to 1.76	-1.97	-0.58	-2.95 to 1.79
BRS Itaim	C. Gigante	1.39	-1.19	-3.56 to 1.18	-1.39	0.18	-2.19 to 2.54
BRS Itaim	Zapp	1.64	-0.94	-3.31 to 1.43	-1.64	-0.25	-2.62 to 2.12
				CR			
		$\bar{Y}$		D			SCI
BRS Tumucumaque	C. Gigante	3.00		-0.39			-1.57 to 0.78
BRS Tumucumaque	Zapp	3.39		0.01			-1,16 to 1,19
BRS Cauamé	C. Gigante	3.12		-0.27			-1,45 to 0,90
BRS Cauamé	Zapp	2.90		-0.49			-1.67 to 0.69
BRS Guariba	C. Gigante	2.90		-0.49			-1.67 to 0.68
BRS Guariba	Zapp	2.97		-0.42			-1.60 to 0.75
BRS Itaim	C. Gigante	3.38		-0.01			-1.19 to 1.16
BRS Itaim	Zapp	3.16		-0.24			-1.41 to 0.94

The highest mean values of A_r and CR were registered in the combination of cultivar BRS Tumucumaque with cultivar Zapp. The A_r of 2.58 and CR of 3.39 indicate that the radish cultivar Zapp, when in combination with the vegetable cowpea Tumucumaque, showed the strongest competition among the tested combinations. In addition, the confidence interval for this combination had a large part of positive values, leading us to infer that this combination is the most competitive one and most efficiently uses the environmental resources.

On the other hand, the highest mean value of A_{vc} (-1.39) as well as the highest difference (0.18) between the averages of the i-th combination and the maximum among the averages of the other combinations was registered in the combination of cultivar BRS Itaim with cultivar Crimson Gigante.

This also demonstrates that a lower value of the competition index, obtained by combining the cultivar BRS Itaim with the cultivar C. Gigante, was translated into low agronomic and economic efficiency, leading us to affirm that the combination of cultivar BRS Itaim with cultivar C. Gigante had the lowest agroeconomic efficiency among the tested combinations.

The aggressiveness index of the cultures and the competitive ratio are important indices to determine the competition ability of a culture or of an intercropping system, portraying which culture will be dominant or which one will be dominated in the system. The CR provides the exact degree of competition by indicating the number of times in which the dominant species is more competitive than the dominated species.

Thus, the aggressiveness index of the radish in the tested combinations was positive and that of the vegetable cowpea negative, showing that the radish was the dominant crop and the vegetable cowpea was the dominated crop, demonstrating that when $A > 0$, the culture's ability to use the environmental resources is superior to that of the other culture when $A < 0$.

The CR also has some advantage over the A index; in an intercropping system, the culture with the higher CR makes better use of the environmental resources.

The shading of one culture over the other may contribute to the reduction of its yields (Belel, Halim, Rafii, & Saud, 2014; Karanja, Kibe, Karogo, & Mwangi, 2014). In this study, cowpea plants occasionally shadowed part of the plants in the side rows in the radish strip. However, this did not interfere with the productivity of the radish crop. In turn, it should be added that in an intercropping system, the environment of the plants in relation to shading needs adjustments to avoid strong interspecific competition. In the case under study, all combinations of cowpea cultivars with radish cultivars were tested in a strip-intercropping system (four rows of cowpea alternating with four rows of radish) to minimise competition for light.

Studies on the intercropping of cowpea with sorghum (Oseni, 2010), cowpea with castor bean (Pinto, Sizenando, Cysne, & Pitombeira, 2011) and lima bean with maize (Ajala, Awodun, Adeyemo, & Dada, 2019) reported that cowpea and lima beans were dominated crops, which is in agreement with our findings when cowpea was associated with radish.

Conclusions

The cowpea cultivar BRS Tumucumaque, when combined with the radish cultivar Zapp, provided the highest agro-economic efficiency in a semi-arid environment. The complementarity and sustainability of the intercropping systems of cowpea and radish were observed using the results of the Hsu test applied to the indices of agro-economic efficiency and of competition. Radish was the dominant crop.

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

Ajala, R. O., Awodun, M. A., Adeyemo, A. J., & Dada, B. F. (2019). Assessment of wood ash application on yield advantage indices of maize and lima beans in an Intercrop. *Journal of Experimental Agriculture International, 34*(1), 1-11. doi: 10.9734/jeai/2019/v34i130163

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M., & Sparovek. (2014). G. Koppen´s climate classification map for Brazil. *Metereologische Zeitschrift, 22*(6), 711-728. doi: 10.1127/0941-2948/2013/0507

Banik, P. (1996). Evaluation of wheat (*Triticum aestivum*) and legume intercropping under 1:1 and 2:1 row-replacement series system. Journal of Agronomy and Crop Science, 176(5), 289-294. doi: 10.1111/j.14 39-037X.1996.tb00473.x

Belel, M. D., Halim, R. A., Rafii, M. Y., & Saud, H. M. (2014). Intercropping of corn with some selected legumes for improved forage production: A review. *Journal of Agricultural Science, 6*(3), 48-62. doi: 10. 5539/jas.v6n3p48

Bezerra, F., Neto, & Robichaux, R. H. (1997). Spatial arrangement and density effects on an annual cotton/cowpea/maize intercrop. II. Yield and biomass. *Pesquisa Agropecuária Brasileira, 32*(10), 1029-1037.

Bezerra, F., Neto, Gomes, E. G., Araújo, R. R., Oliveira, E. Q., Nunes, G. H. S., Grangeiro, L. C., & Azevedo, C. M. S. B. (2010). Evaluation of yield advantage indexes in carrot-lettuce intercropping systems. *Interciencia, 35*(1), 59-64.

Cecílio, A. B., Fº., A. B., Bezerra, F., Neto, Rezende, B. L. A., Barros, A. P., Jr., & 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.

Chen, P., Du, Q., Liu, X., Zhou, L., Hussain, S., Lei, L.,... Yong, T. (2017). Effects of reduced nitrogen inputs on crop yield and nitrogen use efficiency in a long-term maize-soybean relay strip intercropping system. *PloS One, 12*(9), 1-19. doi: 10.1371/journal.pone.0184503

Costa, A. P., Bezerra, F., Neto, Silva, M. L., Lima, J. S. S., Barros, A. P., Jr., & Porto,

V. C. N. (2017). Intercropping of carrot x cowpea-vegetables: evaluation of cultivar combinations fertilized with roostertree. *Revista Caatinga, 30*(3), 633-641, 2017. doi: 10.1590/1983-21252017 v30n311r

Equipe Estatcamp (2014). *Software Action.* São Carlos: Estatcamp - Consultoria em estatística e qualidade. Recuperado de http://www.portalaction.combr/

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

Gendy, A. S. H., Nosir, W. S., & Nawar, D. A. S. (2017). Evaluation of competitive indices between roselle and cowpea as influenced by intercropping system and bio-fertilization type. *Middle East Journal of Agriculture Research, 6*(1), 199-207.

Ghosh, P. K., Das, A., Saha, R., Kharkrang, E., Tripathi, A. K., Munda, G. C., & Ngachan, S. V. (2010). Conservation agriculture towards achieving food security in North East India. *Current Science, 99*(7), 915-921.

He, H., Yang, L., Fan, L., Zhao, L., Wu, H., Yang, J., & Li, C. (2011). The effect of intercropping of maize and soybean on microclimate. In D. Li, & Y. Chen (Eds.), *Computer and computing technologies in agriculture* (v. 369, pp. 257-263). Berlin, Heidelberg: Springer. doi: 10.1007/978-3-642-27278-3_27

Hiebsch, C. K., & McCollum, R. E. (1987). Area x time equivalency ratio: a method for evaluating the productivity of intercrops. *Agronomy Journal, 79*(1), 15-22. doi: 10.2134/agronj1987.00021962007900010004x

Himmelstein, J., Ares, A., Gallagher, D., & Myers, J. (2017). A meta-analysis of intercropping in Africa: impacts on crop yield, farmer income, and integrated pest management effects. *International Journal of Agricultural Sustainability, 25*(1), 1-10. doi: 10.1080/14735903.2016.1242332

Hsu, J. C. (1981). Simultaneous confidence intervals for all distances from the “best”. *Annals of Statistics, 9*(5), 1026-1034.

Iqbal, M. A., Hamid, A., Ahmad, T., Siddiqui, M. H., Hussain, I., Ali, S.,... Ahmad, Z. (2019). Forage sorghum-legumes intercropping: effect on growth, yields, nutritional quality and economic returns. *Bragantia, 78*(1), 82-95. doi: 10.1590/1678-4499.2017363

Karanja, S. M., Kibe, A. M., Karogo, P. N., & Mwangi, M. (2014). Effects of intercrop population density and row orientation on growth and yields of sorghum-cowpea cropping systems in semi-arid Rongai, Kenya. *Journal of Agricultural Science, 6*(5), 34-43. doi: 10.5539/jas.v6n5p34

Kebebew, S., Belete, K., & Tana, T. (2014). Productivity evaluation of maize-soybean intercropping system under rainfed condition at Bench-Maji Zone, Ethiopia. *European Researcher, 79*(7), 1301-1309. doi: 10.13187/er.2014.2.1301

Lima, J. S. S., Bezerra, F., Neto, Negreiros, M. Z., Ribeiro, M. C. C., & Barros, A. P., Jr. (2010). Productive performance of carrot and rocket cultivars in strip-intercropping system and sole crops. *Agrociência, 44*(5), 561-574.

McGilchrist, C. A., & Trenbath, B. R. (1971). A revised analysis of plant competition experiments. *Biometrics, 27*(3), 659-671. doi: 10.2307/2528603

Negreiros, M. Z., Bezerra, F., Neto, Porto, V. C. N., & Santos, R. H. S. (2002). Cultivares de alface em sistemas solteiro e consorciado com cenoura em Mossoró. *Horticultura Brasileira, 20*(2), 162-166. doi: 10.1590/S0102-05362002000200008

Oseni, T. O. (2010). Evaluation of sorghum-cowpea intercropping productivity in Savanna Agro-Ecology using competition indices. *Journal of Agricultural Science, 2*(3), 229-233. doi: 10.5539/jas.v2n3p229

Pinto, C. M., Sizenando, F. A., Fº., Cysne, J. R. B., & Pitombeira, J. B. (2011). Produtividade e indices competição da mamona consorciada com gergelim, algodão, milho e feijão caupi. *Revista Verde de Agroecologia e Desenvolvimento Sustentável, 6*(2), 75-85.

Qasem, J. R. (2011). *Herbicides applications: problems and considerations, herbicides and environment.* Croatia: IntechOpen.

Willey, R. W. (1979). Intercropping: its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstracts, 32*(1), 1-20.

Willey, R. W., & Rao, M. R. (1980). A competitive ratio for quantifying competition between intercrops. *Experimental Agriculture, 16*(2), 117-125. doi: 10.1017/S0014479700010802

Xu, B., Li, F. M., & Shan, L. (2008). Switchgrass and milkvetch intercropping under 2:1 row-replacement in semiarid region, northwest China: aboveground biomass and water use efficiency. *European Journal of Agronomy, 28*(3), 485-492. doi: 10.1016/j.eja.2007.11.011