New statistical approaches to analyze data from intercropping experiments

Novas abordagens estatísticas na análise de experimentos de consórcios

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ABSTRACT

Discussed this and other statistical methods for processing simulated data from the Jatropha x Cowpea intercropping system, in order to compare them with others and with the conventional method, and to recommend a general application method in experiments with intercropping systems. The experimental design was randomized blocks with four replications. The treatments were arranged in a 2 x 7 factorial scheme, corresponding to two levels (90 and 100% of the recommended population in sole cropping - RPSC) of jatropha, with 4 x 2 m and seven levels (40; 50; 60; 70; 80; 90 and 100% of RPSC) of cowpea. The variables analyzed in jatropha were intercropping yield (t ha^{-1}), mass of seeds (t ha^{-1}), oil yield (L ha^{-1}) and gross income (R\$). In cowpea, the variables were yield (t ha^{-1}) and gross income (R\$). The evaluated methodologies were ANOVA with application of Tukey test, multivariate analysis of variance, bivariate analysis of variance, land use efficiency index (LUE), competitiveness index, DEA efficiency index, multicriteria decision support analysis of Copeland and Ward's hierarchical cluster analysis. The index LUE$_{TOTAL}$ associated with bivariate graphical analysis or hierarchical cluster analysis can be successfully applied in the processing of data from any intercropping system. Thus, LUE$_{TOTAL}$ and multivariate analysis are recommended as complementary methods.

Keywords: Land use efficiency index; Data envelopment analysis; Multicriteria decision support method; Bivariate analysis of variance; Univariate analysis of variance;

RESUMO

Discutiu-se este e outros métodos estatísticos de processamento para dados simulados do sistema consorciado *Jatropha* x Feijão-caupi, a fim de compará-los com o método convencional, objetivando recomendar um método de aplicação geral em experimentos com sistemas consorciados. O delineamento experimental foi em blocos casualizados com quatro repetições. Os tratamentos foram arranjados em esquema fatorial 2 x 7, correspondendo a dois níveis (90 e 100% da população recomendada em monocultivo - RPSC) de pinhão-manso, com 4 x 2 m, e sete níveis (40; 50; 60; 70 ; 80; 90 e 100% de RPSC) de feijão-caupi. As variáveis analisadas no pinhão-manso foram produtividade em consórcio (t ha^{-}

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¹), massa de sementes (t ha⁻¹), produtividade de óleo (L ha⁻¹) e renda bruta (R$). No feijão-caupi, as variáveis foram produtividade (t ha⁻¹) e renda bruta (R$). As metodologias avaliadas foram ANOVA com aplicação do teste de Tukey, análise multivariada de variância, análise bivariada de variância, índice de eficiência do uso da terra (UET), índice de competitividade, índice de eficiência DEA, análise multicritério de suporte à decisão de Copeland e análise hierárquica de cluster de Ward. O índice UET TOTAL associado à análise gráfica bivariada ou análise hierárquica de agrupamento pode ser aplicado com sucesso no processamento de dados de qualquer sistema consorciado.

Palavras-chave: Índice de eficiência do uso da terra; Análise envoltória de dados; Método multicritério de apoio à decisão; Análise de variância bivariada; Análise de variância univariada;

INTRODUCTION

Definition of hypotheses, planning, experiment conduction and data analysis are essential procedures for the reliability of results obtained in an experiment. Experimental design and analytical procedures for data processing are defined in the experimental planning (DIAS; BARROS, 2009). The previous definition of these procedures is simplified for the basic designs and their arrangements. However, such definition can be complex in the evaluation of more than one source of variation in the same experiment. Tests with intercropped species generate controversies about the definition of the most adequate methodology of data processing.

Intercropping consists in the exploitation of two or more plant species (treatments) simultaneously in the same experimental plot. Studies on the evaluation of methods to determine the efficiency of intercropping systems are recent and scarce. In general, the methods are non-parametric and multivariate. This is due to the multivariate nature of the data resulting from the joint evaluation of agronomic and economic parameters (BEZERRA NETO et al., 2007a). Contrasting with the parametric methods presented by Federer (1993), the statistical analyses at plot level with data envelopment analysis (DEA) was suggested by Bezerra Neto et al. (2007a). The use of this method considers the probability of existence of positive or negative correlation between plots. Conversely, analytical methods that use only the arithmetic mean to process data from intercropping systems are not robust (MELO et al., 2005).

Bezerra Neto et al. (2007a), Bezerra Neto et al. (2007b) and Bezerra Neto et al. (2007c) observed, respectively, effectiveness and ease in the utilization of the DEA method, as well as robustness of the bivariate analysis of variance; viability of the

multicriteria decision support method and of the utilization of agro-economic indicators for biological productivity of intercropping systems. The recommended methods, except that of bivariate analysis, are object of study of the functional relation between resources and products in production engineering. In plant science, there is a lack of application of these methods to process data from intercropping systems.

This study aimed to evaluate new analytical methods to process simulated data of an intercropping system of a perennial species (*Jatropha curcascurcascurcas* L.) and an annual species [(*Vigna unguiculata* (L.) Walp.)], and to recommend one or more of them.

MATERIAL AND METHODS

The experimental design used in the simulation was randomized complete blocks, with four replications. The simulated treatments were arranged in a 2 x 7 factorial scheme. The first factor corresponded to two levels (90 and 100%) relative to the recommended population for the sole cropping (RPSC) of the perennial species, at 4 x 2 m spacing, and for the oilseed crop Jatropha (*Jatropha curcascurcascurcas* L.) (DIAS *et al*., 2007). The second factor was composed of seven levels (40, 50, 60, 70, 80, 90 and 100% RPSC), whose standard was 50,000 plants, as recommended for cowpea [(*Vigna unguiculata* (L.) Walp.)] (CARDOSO *et al*., 1997).

The variables analyzed in *J. curcas* were yield in intercropping (t ha^{-1}), mass of seeds (t ha^{-1}), oil yield (L ha^{-1}), based on the maximum content (38.9%) reported by Kaushik *et al*. (2007), and gross income, estimated from R$ 1.85 L^{-1} of oil (BARROSO *et al*., 2014). In the cowpea crop, the analyzed variables were yield and gross income, estimated from the value of R$ 2.30 kg^{-1}.

The experimental data were obtained by simulation using the *rnorm()* function of the R software version 3.2.0. The function was entered into the expression *y<-matrix(rnorm((), mean = (), sd = sqrt()))* to obtain the estimated values of the plots, where y is a vector of four pseudo-random numbers, *mean* is the mean established and *sd = sqrt* corresponds to the variance in the normal distribution, so that the distribution of plots (Y_i) in each treatment is approximately normal, i.e., $(Y_{11}, Y_{12}, \ldots, Y_{27}) \sim N\{\mu, \sigma^2\}$.

For the utilization of the function *rnorm()*, the mean yields of treatments with *J. curcas* in intercropping and the respective variances ($\hat{\sigma}^2 = 1.00$ and $\hat{\sigma}^2 = 0.01$) were arbitrarily determined. The maximum yield of *J. curcas* in intercropping corresponded

to the mean yield in sole cropping (5 t ha^{-1}) (TEIXEIRA, 2005). The maximum yield for cowpea, considering the grain yield in the rainfed cultivation in the Piauí state, was approximately 0.03 t ha^{-1} (IBGE, 2006). The mean yields of *J. curcas* with 90 and 100% RPSC in intercropping with 100, 90, 80, 70, 60, 50 and 40% RPSC of cowpea, were respectively T1 ($\overline{X} = 2.39$), T2 ($\overline{X} = 2.66$), T3 ($\overline{X} = 2.95$), T4 ($\overline{X} = 3.28$), T5 ($\overline{X} = 3.65$), T6 ($\overline{X} = 4.05$), T7 ($\overline{X} = 4.50$), T8 ($\overline{X} = 2.66$), T9 ($\overline{X} = 2.95$), T10 ($\overline{X} = 3.28$), T11 ($\overline{X} = 3.65$), T12 ($\overline{X} = 4.05$), T13 ($\overline{X} = 4.50$) and T14 ($\overline{X} = 5.00$). A loss of 10% in *J. curcas* yield for every 10% increment in cowpea population was arbitrarily considered.

The statistical methods used for data processing were univariate analysis of variance (ANOVA) (FEDERER, 1993; FISHER, 1971), with Tukey test ($p < 0.05$), multivariate analysis of variance (MANOVA), bivariate analysis of variance (FEDERER, 1993; PEARCE; GILLIVER, 1979), land use efficiency index (LUE) of Willey (1979), index of competitiveness (IC) of Willey and Rao (1981), DEA (*Data Envelopment Analysis*) efficiency index of Charnes and Cooper (1962), applied to the treatment means after the ANOVA, multicriteria decision support analysis of Copeland and Ward's hierarchical cluster analysis (WARD, 1963).

The univariate analysis of variance (ANOVA) and Tukey test were processed with the R software version 3.2.0 (R Core Team, 2014). Bivariate analysis of variance was conducted using the statistical module of Excel for processing the method of Pearce and Gilliver (1979). The variables Y_A and Y_B relative to the yields in the intercropping of *J. curcas* (YJIC) and cowpea (YCIC) were transformed. The mean square of the residual of the ANOVA of YJIC (MSYJIC), mean square of the residual of the ANOVA of YCIC (MSYCIC) and mean product of the residual of the analysis of yields of *Jatropha* and cowpea in intercropping (MPYJICCIC) were used (1):

$$(1) \ \text{MPYJICCIC} = \frac{\text{MSYCIC} - \text{MSYJIC} - \text{MSYJICCIC}}{2}$$

The variables X_A and X_B, not correlated, were, respectively obtained by 2 and 3:

$$(2) \ X_A = \frac{Y_A}{\sqrt{\text{MSYJIC}}}; (3) \ X_B = \frac{Y_A - (\text{MPYJICCIC } Y_B)}{\sqrt{\frac{\text{MSYCIC} - \text{MPYJICCIC}}{\text{MSYJIC}}}}$$

meeting the restrictions of orthogonality $\hat{\sigma}^2_{X_A} = \hat{\sigma}^2_{X_B} = 1$ and $\text{COV}(X_A, X_B) = 0$.

The efficiency indices based on efficient land use (LUE) (WILLEY, 1979) were calculated using Excel. LUE was obtained by 4:

$$(4) \ \ LUE = \frac{Y_{YJIC}}{Y_{YJSC}} + \frac{Y_{YCIC}}{Y_{YCSC}}$$

where, Y_{YJIC} is the grain yield of *J. curcas* in intercropping and Y_{YJSC} is its yield in sole cropping; Y_{YCIC} is the grain yield of cowpea in intercropping and Y_{YCSC} is its yield in sole cropping. The partial LUE of *J. curcas* (LUE_{PARTJ}) and cowpea (LUE_{PARTC}) were respectively obtained by 5 and 6:

$$(5) \ \ LUE_{PARTJ} = \frac{Y_{YJIC}}{Y_{YJSC}}; (6) \ \ LUE_{PARTC} = \frac{Y_{YCIC}}{Y_{YCSC}}$$

where, LUE_{PART} close to 1 indicates efficiency of the intercropping system in comparison to the sole cropping system. The index of competitiveness between crops of Willey and Rao (1981) was obtained by 7:

$$(7) \ \ IC = \frac{LUE_{PARTC}}{LUE_{PARTJ}}$$

The productive efficiency of each plot was obtained using the DEA model with constant returns to scale (COOPER *et al*., 2004), using the application ISYDS – Integrated system for decision support (ANGULO MEZA *et al*., 2005a), with unit inputs (LOVELL; PASTOR, 1999). For each mean of treatments, model 8 was processed:

$$(8) \ \ Max_{h_o} = \frac{\sum_{j=1}^{r} u_j \, y_{jk}}{\sum_{i=1}^{s} v_i \, x_{ik}}$$

with restrictions (9, 10 and 11):

$$(9) \ \ \frac{u_j y_{jk}}{v_i x_{ik}} \leq 1 \, ; (10) \ \ v_i \geq 0; (11) \ \ u_j \geq 0$$

where, v_i and u_j are the weights of inputs (resources or treatments) i (i = 1, ..., r) and outputs (products or variables) j = 1, ..., s, respectively. The unknowns of the model are x_{ik}: value of the resource i (i = 1...s) for each plot k (k = 1...n); y_{jk}: value of the product j (j = 1...r) (output of the DMU), for the plot k (k = 1, ..., O); and O is the plot in analysis. Maximum efficiency was determined by linearizing the fractional model (CHARNES; COOPER, 1962) (12): (12) $MaxZ = \sum_{j=1}^{r} \mu_j y_{jo}$; with restrictions to the model (13, 14, 15 and 16): (13) $\sum_{i=1}^{s} V_i x_{io} = 1$; (14) $\sum_{j=1}^{r} \mu_j y_{jk} - \sum_{i=1}^{s} V_i x_{ik} \leq 0$; and (15) $\mu_i \geq 0$ and (16) $V_i \geq 0$. To enter the variables into the model, orthogonal transformation was carried out through the method of Pearce and Gilliver (1979).

Multicriteria analysis through the Copeland method was performed with the software *Preferências Ordinais Agregadas* – WebPROA. Pair-wise comparison of means was made and the Condorcet decision matrix was obtained for 14 treatments. Each element a_{ij} of the matrix was obtained by attributing 0 when the element i (for i = 1, 2, ..., i-th alternative) is equal to j (j = 1, 2, ..., j-th alternative); 1 when the element i is preferred over j and -1 when an element i is preferred over j. Ranks were defined based on the sums of the lines of the Condorcet decision matrix for each treatment. The method was applied to 14 criteria referring to the treatments (T1, T2, ..., T14).

Cluster analysis was carried out with the hierarchical method of Ward (1963), using the R software version 3.2.0. (R Core Team, 2014). All the processing was carried out at the data laboratory of the Federal University of Piauí (UFPI), Campus *Professora Cinobelina Elvas* (CPCE), municipality of Bom Jesus, Piauí, Brazil.

RESULTS AND DISCUSSION

Based on the analysis of variance (ANOVA), the interaction between sole cropping systems of *J. curcas* and cowpea had significant effect ($p < 0.01$) on all variables. For *J. curcas* in intercropping, significant effect occurred on yield, gross income, mass of seeds and oil yield ($p < 0.05$). For cowpea in intercropping, yield and gross income ($p < 0.01$) were affected (Table 1).

Table 1 – Summary of analysis of variance and Tukey test for simulated data of *J. curcas* (JS) and cowpea (CS) in sole cropping and in intercropping (JS x CS)

SV	DF	[1]F					
		YJIC	GIJIC	MSJIC	OYJIC	YCIC	GICIC
J. curcas (JS)	1	7.41*	7.41*	7.38*	7.41*	124.35**	126.39**
Cowpea (CS)	6	1.45	1.45	1.46	1.45	4.95**	4.99**
JS x CS	6	6.96**	6.96**	6.97**	6.96**	5.42**	5.29**
Blocks	3	0.80	0.80	0.81	0.80	0.22	0.306
Residual	39	-	-	-	-	-	-

CP (%)	YJIC		MSJIC		OYJIC	
	[2]I	[3]II	I	II	I	II
100	2.04aB	2.27aC	1.33aB	1.80aC	53.51aB	72.52aC
90	2.56aB	3.31aBC	1.66aB	2.15aBC	67.21aB	86.82aBC

CP (%)	GIJIC		YCIC		GICIC	
80	3.12aAB	3.83aABC	2.03aAB	2.49aABC	81.97aAB	100.59aABC
70	3.78aAB	3.91aABC	2.27aAB	2.54aABC	91.74aAB	102.69aABC
60	3.52aAB	3.92aABC	2.29aAB	2.55aABC	92.33aAB	102.95aABC
50	3.52aAB	5.09aAB	2.46aAB	3.30aAB	99.15aAB	133.44aAB
40	5.13aA	5.90aA	3.37aA	3.83aA	134.69aA	154.95aA

	I	II	I	II	I	II
100	98.99aB	134.17aB	0.03aA	0.02aC	443.4cA	624cC
90	124.34aB	160.61aAB	0.02bA	0.18aB	462bA	4236aB
80	151.64aAB	186.09aAB	0.02bA	0.19aB	462bA	4434aB
70	169.71aAB	189.97aAB	0.02bA	0.21aB	498bA	4980aB
60	170.80aAB	190.46aAB	0.02bA	0.23aAB	552bA	5520aAB
50	183.42aAB	246.87aAB	0.04bA	0.26aAB	648bA	6240aAB
40	249.17aA	286.29aA	0.02bA	0.35aA	846bA	8460aA

[1] F test; * Significant at 0.05 probability level by F test; ** Significant at 0.01 probability level by F test; CP(%) – cowpea population. [2] 90% of the recommended population of *J. curcas*; [3] 100% of the recommended population of *J. curcas*. JS - *J. curcas* in sole cropping, CS – Cowpea in sole cropping, YJIC – yield of *J. curcas* in intercropping, GIJIC – gross income of *J. curcas* in intercropping, MSJIC - mass of seeds of *J. curcas* in intercropping, OYJIC - oil yield of *J. curcas* in intercropping, YCIC - yield of cowpea in intercropping and GICIC - gross income of cowpea in intercropping. Means followed by equal letters, lowercase in the row and uppercase in the column, do not differ at 0.05 probability level by Tukey test.

For the interaction, the best yields (t ha^{-1}) of *J. curcas* at 90 and 100% RPSC were obtained with 40% RPSC of cowpea. However, there was no statistical difference between both population densities. Yields of *J. curcas* at 90 and 100% RPSC were up to 2.5 times higher than the yields with 100% RPSC of cowpea.

The same contrast was observed for mass of seeds, oil yield and gross income of *J. curcas* in intercropping, because the analysis of biological efficiency of intercropping systems considers yield as a character of main importance. However, some species have particularities that must be considered before the recommendation of an intercropping system. In the case of *J. curcas*, the yield of oil extracted from the seed

is directly associated with the viability of the system. Therefore, the hypothesis that yield cannot be associated proportionally with the maintenance of the mean oil content in the seeds, after introducing cowpea in the plot, needs to be verified. In the present study, however, the correlation between yield and oil yield of *J. curcas* in intercropping was r = 0.99.

The best yields of cowpea were obtained with 40% RPSC at 90 and 100% RPSC of *J. curcas*. Thus, it becomes evident the interference exerted by *J. curcas* on cowpea yield. On the other hand, the opposite was not true. Interference of the same nature was reported by Matos *et al*. (2014). Evaluating 4-year-old *J. curcas* plants spaced by 4 x 2 m, intercropped with soybean planted at 1 m from the row of *J. curcas*, these authors observed yield loss of approximately 50% for soybean. Conversely, Souza *et al*. (2013) observed loss of approximately 17% for the bean crop planted at 1.5 m from the row of 6-month-old *J. curcas* plants, at spacing of 4 x 2 m. In this case, the shading on the bean crop was reduced and there was a vigorous performance of *J. curcas*.

Intercropping with forage species has also been studied. Nonetheless, as for food crops, it still requires multidisciplinary investigation. In this process, the use of *J. curcas* as energy crop integrating agrosilvicultural and agrosilvopastoral systems represents an alternative for sustainability of the exploitation by family farmers.

Evaluating different arrangements of *J. curcas* plants, Muller *et al*. (2014) observed greater vegetative development in plants at spacing of 6 x 3 m. In a subsequent season, greater gain in plant height was obtained at the spacing of 8 x 2 m. In the evaluated seasons, the intercropping of *J. curcas* x corn x pasture led to greater development of *J. curcas* plants with respect to all variables evaluated. Silva *et al*. (2012) observed viability in the intercropping of grass and leguminous species planted at 0.5 m from *J. curcas* plants, at spacing of 3 x 2 m.

The use of phytotechnical and economic variables for the simulation of plots had consistent results. In general, these results were consistent and corroborated those found in the literature. The gain with the prediction of the performance of the 14 combinations tested, without actually having the field experiment, reinforces the accuracy of the technique used. Undoubtedly, the simulation technique adopted can be used as an auxiliary tool to select or exclude similar treatments.

For graphical evaluation, multivariate analysis of variance (MANOVA) was carried out (Table 2).

Table 2 - Summary of the multivariate analysis of variance of the combined yields of the *J. curcas* x cowpea intercropping system

SV	[1]Λ (Wilks)	[1]Pillai	[2]Approximation	Pr > F
J. curcas (JS)	0.34	0.66	49.00	0.0001
Cowpea (CS)	0.79	0.21	6.65	0.0001
JS x CS	0.50	0.50	24.78	0.0001
Blocks	0.97	0.03	0.83	0.4437

[1] Tests for the null hypothesis of the MANOVA; [2] Approximation of the Snedecor F-test

Based on the tests for the vectors of treatment means, significant differences ($p < 0.01$) were found by the criteria of Wilks ($\Lambda < 1$) and Pillai for JS and CS yields and for the interaction between the population densities evaluated (JS x CS).

The result of the MANOVA corroborates the one obtained with the ANOVA for the vectors and their interaction. This result allowed the two-dimensional analysis of treatment scores (Figure 1).

Figure 1 – Non-orthogonal coordinates of treatments [$T_n(X_A; X_B)$] equivalent to the combined yields of YJIC and YCIC [T1 (2.05; 0.74), T2 (2.57; 0.95), T3 (3.13; 1.16), T4 (3.79; 1.41), T5 (3.53; 1.31), T6 (3.53; 1.29), T7 (5.14; 1.92), T8 (2.28; 0.84), T9 (3.32; 1.05), T10 (3.84; 1.24), T11 (3.92; 1.25), T12 (3.93; 1.23), T13 (5.10; 1.64), T14 (5.92, 1.84)] I, II, III and IV: Quadrants one (Q I), two (Q II), three (Q III) and four (Q IV) subdividing the total graph area into four subareas with equal dimensions.
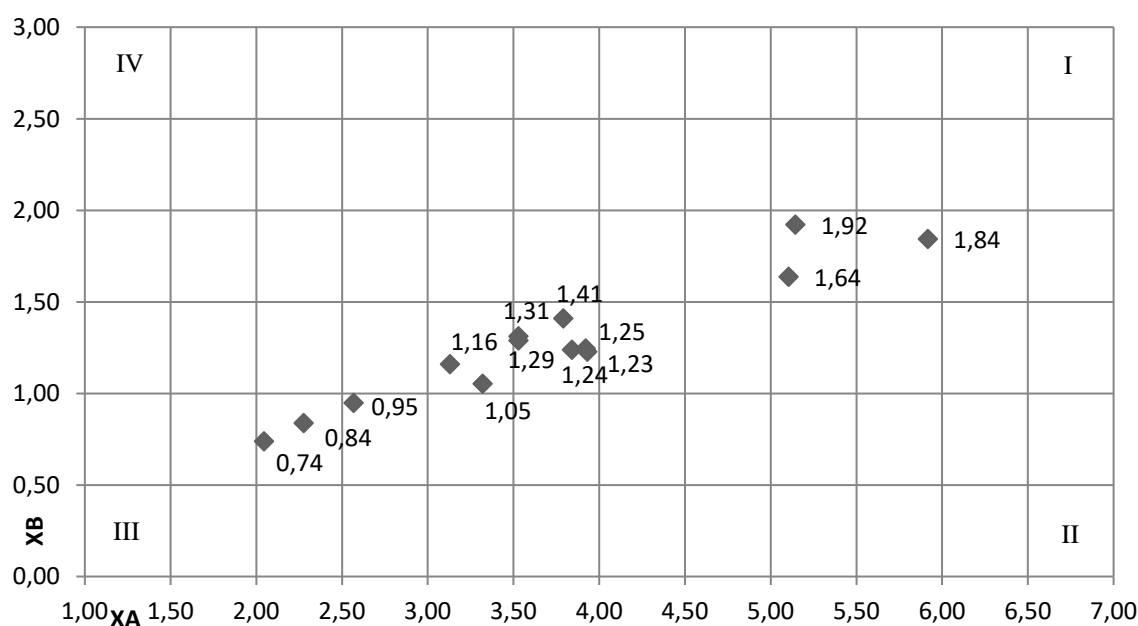
Fonte: the author.

The descriptive analysis of the dispersion graph (Figure 1) ranks T14 as the best combination for the yield of *J. curcas* in intercropping. Other two treatments were also grouped in Q I (T7 and T13), representing alternatives for gains of yield.

The quality and applicability of the two-dimensional analysis of intercropping data were reinforced by Bezerra Neto *et al*. (2007a) in a comparative study between analysis methodologies for the carrot x lettuce system. However, studies evaluating the applicability and efficiency of statistical methods to process data from intercropping systems are still incipient.

Efficiency indices and non-parametric multivariate methods have been used as auxiliary tools for inference on intercropping systems. Indices based on the efficient use of the land exploited per plot (WILLEY, 1979; WILLEY; RAO, 1981) and on data envelopment analysis (CHARNES; COOPER, 1962), as well as the ranking of treatments obtained by the multicriteria decision support method of Copeland (GOMES; BEZERRA NETO, 2008) were obtained in the present study (Table 3).

Table 3 - Intercropping efficiency indices resulting from data envelopment analysis (DEA), efficient land use (LUE_{TOTAL}) and index competitiveness (IC), and classification of Copeland ranks using the variables yield of *J. curcas* in intercropping and gross income of *J. curcas* in intercropping for decision-making.

CP (%)	DEA		LUE_{TOTAL}		IC	
	I	II	I	II	I	II
100	0.35	0.47	1.00	2.05	1.76	16.85
90	0.43	0.56	1.13	7.18	1.67	15.92
80	0.53	0.66	1.39	7.20	1.46	15.65
70	0.59	0.66	1.40	7.68	1.25	8.96
60	0.60	0.65	1.52	8.33	1.06	8.66
50	0.64	0.86	1.79	9.22	0.88	6.33
40	0.87	1.00	1.90	12.53	0.74	0.74

Copeland ranks												
1	2	3	4	5	6	7	8	9	10	11	12	13
T14	T7	T13	T12	T11	T10	T6	T4	T5	T9	T3	T8	T2	T1

CP (%) : cowpea population

The descriptive analysis of the absolute values of the indices DEA, LUE$_{TOTAL}$ and IC kept T14 as the most efficient combination. Consequently, the reduction in the mean efficiency of the treatments was observed as PF (%) increased. Highest DEA efficiency indices were found for T7 and T14, respectively 0.87 and 1.00.

For LUE$_{TOTAL}$, T7 and T14 showed the best performance with respect to land use by the intercropped species, respectively 1.90 and 12.53. LUE$_{TOTAL}$ higher than 1 suggests that the intercropping is advantageous over sole cropping (CAMILI, 2013). In general, LUE is the most used index by researchers to assess the viability of intercropping systems (BEZERRA NETO; GOMES, 2008)

As observed for DEA and LUE$_{TOTAL}$, the best IC values were obtained by the treatments T8 and T14, respectively 0.74 and 0.74. Contrasting with DEA and LUE$_{TOTAL}$, IC values lower than 1 indicate reduced interference of the secondary crop on the yield of the main one. Nevertheless, Bezerra Neto *et al*. (2007c) pointed out that IC should not be considered as a single criterion and the intercropping system should have economic viability for both crops.

Bezerra Neto *et al*. (2007a) highlight that indices resulting from the DEA CCR model have univariate nature and can be processed by parametric techniques. However, this study found that only the absolute values of the indices allowed the ranking of the treatments and that the results did not differ from those obtained with the methods ANOVA, MANOVA and two-dimensional graphic analysis.

The convergent results of the indices are associated with the use of the mean as central tendency statistics of the treatments. LUE$_{TOTAL}$ and IC are indices that require strict meeting of parametric assumptions; however, the same does not apply to the DEA index (MELO *et al*., 2005). According to Melo *et al*. (2005), DEA models and the multicriteria decision support method of Copeland are non-parametric alternatives for processing (MELO *et al.*, 2005). In the present study, the hypothesis of application of the DEA CCR model to the plots was preferred over treatment means. The procedure was adopted because the experiment was simulated according to an experimental design and met the basic assumptions of ANOVA and MANOVA. Therefore, the processing at plot level would become redundant with the use of mean values.

Lastly, the result of the multicriteria decision support method of Copeland did not differ from those obtained with the other methodologies evaluated. It brought great value to the analysis, considering the obtaining of linear indices through the joint analysis of variables with different natures, in this case, the combination of an economic

variable (RBPC) and an agronomic variable (RPC). The viability of using this non-parametric technique was also found by Bezerra Neto *et al*. (2007b) for carrot-lettuce intercropping.

Ultimately, the applicability of the multivariate hierarchical clustering method of Ward was evaluated (Figure 2).

Figure 2 - Dendrograms of Ward's hierarchical clustering for dissimilarity between groups of treatments of *J. curcas* x cowpea obtained respectively by YJIC; YCIC (A) and YJIC; YCIC; MSJIC; OYJIC; GIJ; YCIC and GIC (B)
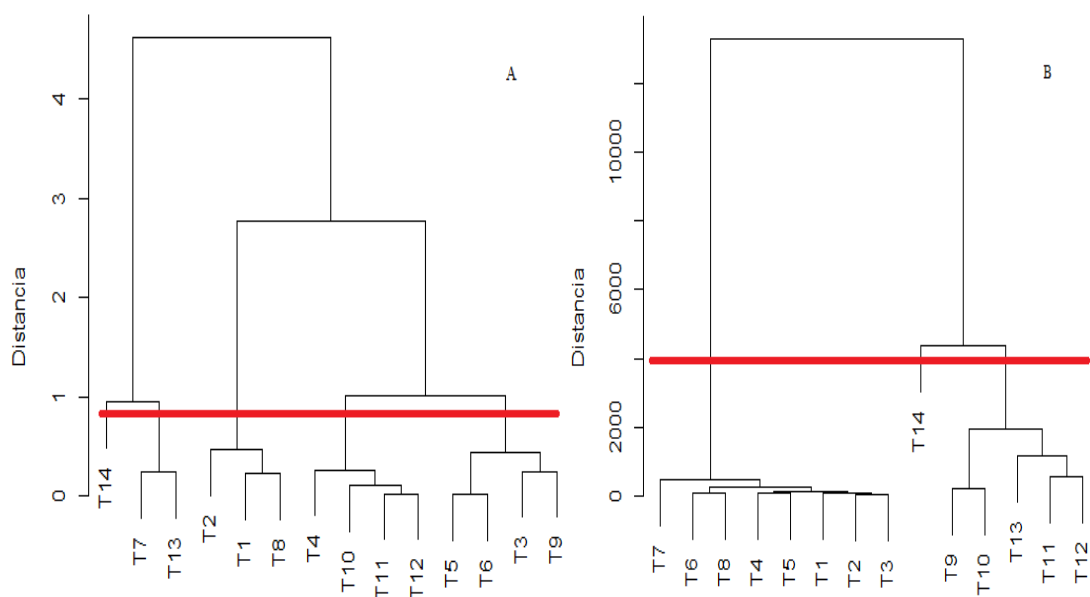
Fonte: the author.

No divergence was observed between the results obtained with the cluster analysis and with the other methodologies evaluated. Among the five groups formed in the dendrogram A, T14 defined group I and had the highest means for *J. curcas* (5.90) and cowpea (0.35). The other groups formed were composed of the treatments T7 and T13 (group II), T2, T1 and T8 (group III), T4, T10, T11 and T12 (group IV) and T5, T6, T3 and T9 (group V). Although the treatments T14, T7 and T13 were grouped in the QI of the bivariate analysis graph, the method does not consist in a cluster analysis. Thus, after applying the procedure of Ward, only T14 defined group I in Figure 2A and B.

The dendrogram A showed group II formed by T7 and T13, indicating similarity between the treatments, already suggested in the QI of the bivariate analysis. Considering all variables determined in the dendrogram B, T14 remained as the best combination between *J. curcas* and cowpea. In B, only three dissimilar groups formed, suggesting that the increase in the number of variables analyzed, simultaneously, favored the grouping of similar combinations and highlighted the divergent one, T14.

Using the hierarchical clustering method allowed the observation of the effect of multivariate response of the intercropping system. Hierarchical methods are frequently used to discriminate groups of individuals with similar agronomic attributes. In the present study, it was applied to discriminate combinations with similar mean scores and generated coherent and consistent results.

The DEA index and the multicriteria decision support analysis of Copeland also led to coherent and consistent results. However, both are used to evaluate production systems by operational research, a research line of the production engineering. Consequently, further studies are needed on the processing of data of intercropping experiments in agriculture.

CONCLUSION

The index LUE_{TOTAL}, associated with bivariate graphical analysis or hierarchical cluster analysis, can be applied in the processing of data from any intercropping system.

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