Intercropping arugula with aromatic condiment species affords better yields, biological efficiency and financial return

Consórcio de rúcula com espécies aromáticas condimentares possibilita melhores rendimentos, eficiência biológica e retorno financeiro

El consorcio de rúcula con especies aromáticas aromáticas permite mejores rendimientos, eficiencia biológica y rentabilidad económica

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Abstract
Intercropping affords an increase in productivity by optimising the area used, as well as maximising input use efficiency the financial return of intercroping systems was higher than that observed in the respective individual cultures. Here we show prominently that the financial return of the consortium systems was higher than that observed in the respective individual cultures. The aim of this study was to evaluate the agronomic parameters, biological and productive efficiency, and economic performance of arugula under a single and intercropped system. The study was conducted at the Teaching Garden of the Federal University of Ceará, Brazil, in a randomised block design, with four replications and seven treatments: T1 (single arugula), T2 (arugula intercropped with coriander), T3 (arugula intercropped with parsley), T4 (arugula intercropped with garlic chives), T5 (single coriander), T6 (single parsley) and T7 (single garlic chives). Phytotechnical evaluations were carried out. Biological efficiency was evaluated based on the following factors: land use efficiency index or land equivalent ratio (LER), relative contribution of the arugula crop to the LER (CRC), area time equivalent ratio (RAET) and system productivity index (IPS). For the economic analysis, the following were evaluated: operational production costs (OC; BRL ha^{-1}), gross revenue (GR; BRL ha^{-1}), gross profit (GP; BRL ha^{-1}), rate of return (RR; %) and profitability index (PI;%). The system based on arugula intercropped with coriander showed the best agronomic performance and biological efficiency. Productivity and economic advantage under this intercropped system were also superior to the other treatments.
Keywords: *Eruca sativa* Miller; *Petroselinum crispum*; *Coriandrum sativum*; *Allium tuberosum*; Biological efficiency.

Resumo
A consorciação de culturas favorece o aumento da produtividade por meio da otimização da área utilizada, bem como possibilita a maximização da eficiência de utilização de insumos. Objetivou-se com este trabalho, avaliar os parâmetros agronômicos, a eficiência biológica e produtiva e o desempenho econômico da rúcula em sistema solteiro e consorciado. O estudo foi conduzido na Horta Didática da Universidade Federal do Ceará, no delineamento em blocos casualizados, com quatro repetições e sete tratamentos: T1 (cultivo solteiro de rúcula), T2 (cultivo consorciado de rúcula e coentro), T3 (cultivo consorciado de rúcula e salsa), T4 (cultivo consorciado de rúcula e nirá), T5 (cultivo solteiro de coentro), T6 (cultivo solteiro de salsa) e T7 (cultivo solteiro de nirá). Foram realizadas avaliações fitotécnicas. A eficiência biológica foi avaliada a partir dos seguintes fatores: utilização do índice de uso eficiente da terra ou proporção de terras equivalentes (LER), contribuição relativa da cultura de rúcula ao LER (CRC), razão de área equivalente no tempo (RAET) e índice de produtividade do sistema (IPS). Para análise econômica foram avaliados: custo operacional de produção (CO; R$ ha^{-1}), receita bruta (RB; R$ ha^{-1}), lucro bruto (LB; R$ ha^{-1}), taxa de retorno (TR; %) e índice de lucratividade (IL; %). O sistema de cultivo baseado no consórcio de rúcula e coentro foi o que apresentou o melhor desempenho agronômico e eficiência biológica. A produtividade e vantagem econômica dessa consorciação também foram superiores aos demais tratamentos.
Palavras-chave: *Eruca sativa* Miller; *Petroselinum crispum*; *Coriandrum sativum*; *Allium tuberosum*; Eficiência biológica.

Resumen
La intercalación de cultivos favorece el aumento de la productividad a través de la optimización del área utilizada, además de maximizar la eficiencia del uso de insumos. El objetivo de este trabajo fue evaluar los parámetros agronómicos, la eficiencia biológica y productiva y el desempeño económico de la rúcula en un sistema único e intercalado. El estudio se realizó en el Jardín Didáctico de la Universidad Federal de Ceará, en un diseño de bloques al azar, con cuatro repeticiones y siete tratamientos: T1 (cultivo único de rúcula), T2 (cultivo intercalado de rúcula y cilantro), T3 (cultivo intercalado de rúcula y perejil), T4 (cultivo intercalado de rúcula y nirá), T5 (cultivo único de cilantro), T6 (cultivo único de perejil) y T7 (cultivo único de nirá). Se realizaron evaluaciones fitotécnicas. La eficiencia biológica se evaluó con base en los siguientes factores: uso del índice de uso eficiente de la tierra o proporción de tierra equivalente (LER), contribución relativa del cultivo de rúcula al LER (CRC), razón de área equivalente en el tiempo (RAET) e índice de productividad del sistema (IPS). Para el análisis económico se evaluó lo siguiente: costo operativo de producción (CO; R $ ha-1), ingreso bruto (RB; R $ ha-1), utilidad bruta (LB; R $ ha-1), tasa de retorno (TR;%) e índice de rentabilidad (IL;%). El sistema de cultivo basado en el cultivo intercalado de rúcula y cilantro fue el de mejor desempeño agronómico y eficiencia biológica. La productividad y la ventaja económica de este cultivo intercalado también fueron superiores a los otros tratamientos.
Palabras clave: *Eruca sativa* Miller; *Petroselinum crispum*; *Coriandrum sativum*; *Allium tuberosum*; Eficiência biológica.

1. Introduction

Optimising natural resources with a view to high yields and low production costs has been one of the goals of global agricultural research. As such, intercropped systems employing crops of agronomic interest are seen as a viable alternative, both from the productive and ecological points of view, as well as from the economic perspective (Li *et al*., 2020; Pinheiro *et al*., 2019).

Intercropping is an old technique, used for decades on various annual crops, and showing promising applicability to the cultivation of vegetables. It provides for better use of the production area. In addition, it allows high productivity to be achieved per unit area, affording greater financial return than the invested capital by cultivating two or more species in the same area, where at least part of their cycles occur simultaneously. Intercropped systems need to be economically viable and profitable for implementation by farmers, and their economic indices should also be considered when determining the importance of the intercrop (Maduwanthi *et al*., 2019).

Under an intercropped system, the crops share productive resources in time and space, which allows better use of inputs related to production, such as radiation, nutrients and water, thereby improving productivity and land use efficiency (Meixiu *et al*., 2020). As such, intercropping practices appear to generate win-win solutions. However, intercropped agricultural systems must be carefully evaluated to ensure their viability, and when properly implemented, make it possible to achieve economic stability and biological efficiency in an agroecosystem (Favacho *et al*., 2017; Alcon *et al*., 2020).

Biological efficiency can be analysed using indicators that determine land use efficiency or the land equivalent ratio (LER). In assessing the yield of an intercropped system compared to single crops, LER values greater than 1 indicate that the intercropped system favours growth and yield in the species (Hendges *et al*., 2019; Li *et al*., 2020).

Intercropped systems have been employed in the northeast of Brazil, and among the cultivated vegetables of agronomic interest, arugula (*Eruca sativa* Miller) has been evaluated. This vegetable is characterised as a leafy species of family Brassicaceae, which is appreciated for its subtle pungency. This crop has been gaining space in the market , with marked growth in recent years in both cultivation and consumption. In addition, arugula is known as a plant with the potential for use as an intercrop due to its fast vegetative growth, short cycle and upright architecture, which allow it to adapt to intercropped systems that include aromatic species (Cecílio Filho *et al*., 2008; Abade, 2019).

Similar to arugula, the use of aromatic condiment species in intercropped systems has a high potential for improving the land equivalent ratio during cultivation. This form of production offers an economy of productive resources, such as water and fertiliser, with a more efficient use of labour, which helps to develop the sustainability of the agroecosystem (Hata *et al*., 2019).

As a result, studies that aimed to evaluate the economic viability of cultivating arugula in an intercropped system have been carried out in recent years (Cecílio Filho *et al*., 2008; Bezerra Neto *et al*., 2012). However, despite the good results obtained by researchers, there are few who have evaluated the possibility of intercropping traditional species, such as arugula, with the group of vegetables classified as aromatic condiments. Therefore, the aim of this study was to evaluate the agronomic parameters, biological and productive efficiency, and economic performance of arugula intercropped with aromatic condiment species.

2. Methodology

The study was carried out through field research out at the Teaching Garden of the Department of Plant Science on the Pici Campus of the Federal University of Ceará (UFC), in Fortaleza, Ceará, Brazil, at 03º44' S and 38º34' W, and an altitude of 21 m. According to Köppen, the climate in the region is type As, defined as tropical with dry summers, a mean annual temperature greater than 26°C and mean annual rainfall of approximately 1,450 mm (Alvares et al., 2013).

During the study period the mean minimum temperature was 22.97ºC, the maximum was 31.57ºC, the relative humidity was 71.5% and the accumulated rainfall was 116.20 mm. The data were obtained from the weather station of the Department of Agricultural Engineering on the Pici Campus of UFC.

A randomised block design was used, with seven treatments and four replications. The treatments consisted of T1 - single arugula, T2 - arugula intercropped with coriander, T3 - arugula intercropped with parsley, T4 - arugula intercropped with garlic chives, T5 – single coriander, T6 – single parsley, and T7 – single garlic chives.

For both the single and intercropped arugula, the spacing between plants was 0.2m x 0.2m, with five plants per crop row, giving a total of 35 single plants per plot or 20 intercropped plants per plot, for a plot size of 1.0m x 1.4m.

The single and intercropped coriander, parsley and garlic chives were also spaced 0.2m between crop rows, in plots with an area of 1.0m x 1.4m; for the intercropped treatments, the companion vegetables were arranged across the bed in alternating rows with the arugula. For the coriander and parsley, 4 grams of seed were used per linear metre. The single coriander and parsley were grown in seven rows and the intercropped plants in three rows. Vegetative propagation was used for the garlic chives with tillers from plants grown in the teaching garden of UFC, at a spacing of 0.10m between plants, giving a total of 63 single plants and 27 intercropped plants per plot.

The working area for evaluating the treatments comprised the three central rows of arugula (fifteen plants) in both the single crops and the intercrops. For the intercropped aromatic condiment plants, all three crop rows were considered. However, in the monocrop treatments, the working area consisted of the three central rows. For the coriander and parsley, all plants within a 0.30 m section were harvested and evaluated from two central working crop rows. For the garlic chives, all the plants in the two central rows were harvested for evaluation.

Preparation and fertilisation of the beds was carried out eight days before transplanting the arugula seedlings. The chemical characteristics of the cultivated soil, obtained by analysing the fertility of the 0 to 20 cm layer, showed pH (water) = 7.3, P = 304.5 mg.dm^{-3}, K^+ = 430.0 mg.dm^{-3}, Ca^{2+} = 4.7 cmol$_c$.dm^{-3}, Mg^{2+} = 3.4 cmol$_c$.dm^{-3}, H+Al = 1.2 cmol$_c$.dm^{-3}, SB = 9.2 cmol$_c$.dm^{-3}, CEC = 9.2 cmol$_c$.dm^{-3}, V = 88% and OM = 4.8 g.kg^{-1}.

The following cultivars were used: arugula 'Cultivada', coriander 'Verdão' (Feltrin®), parsley 'Graúda Portuguesa' (Feltrin®) and garlic chives (Takii Seeds®). Planting fertilisation was carried out by incorporating 12 kg.m^{-2} organic compost produced at the site, whose analysis showed pH (water) = 6.9, P = 344.3 mg.dm^{-3}, K^+ = 230.0 mg.dm^{-3}; Ca^{2+} = 10.4 cmol$_c$.dm^{-3}, Mg^{2+} = 6.4 cmol$_c$.dm^{-3}, H+Al = 0.99 cmol$_c$.dm^{-3}, SB = 17.4 cmol$_c$.dm^{-3}, CEC = 17.4 cmol$_c$.dm^{-3} and V = 95%. The coriander and parsley were planted directly in furrows prepared in the soil. The parsley was sown, and the garlic chives were transplanted seven days before transplanting the arugula. The coriander was sown on the same day the arugula was transplanted.

In order to maximise the productive efficiency of the intercrops, the period each species occupied the area was made to coincide, to enable a fair comparison between treatments. As such, usage of the area was established at 65 days, i.e. the time in days of one cycle for harvesting the parsley and garlic chives, since both had the longest occupation cycle in the soil. As a result, while for these two crops only one crop cycle was harvested for evaluation, in the treatments with coriander and arugula, with an average of 30 days occupation, two cycles (two crops) were harvested, regardless of whether they were produced as single crops or intercrops.

The arugula seedlings for the second production cycle were transplanted on the day following the first-cycle harvest, shortly after preparing and fertilising between the rows used in the previous crop. For the coriander, the second sowing took place six days after harvesting the first cycle, immediately after preparing the soil.

The harvests were carried out according to the marketing pattern for each species in the growing region. The arugula was harvested at the end of each vegetative cycle, 55 days after sowing (DAS), or 30 days after transplanting (DAT) the seedlings. For the coriander, the harvest took place at 30 DAS for each of the cultivated crops. The parsley and garlic chives were harvested 65 DAS and 65 DAT respectively.

The evaluations were carried out through quantitative and qualitative approaches (Pereira *et al*., 2018). Quantitative assessments were performed using data collections for phytotechnical and economic assessments. Qualitative assessments were performed using indices that demonstrate biological efficiency in cultivation.

2.1 Phytotechnical variables

Phytotechnical evaluations were carried out 35 days after transplanting the arugula (DAT). The characteristics evaluated in the arugula were: plant height (cm), number of leaves to commercial standards (length greater than 5 cm), leaf fresh weight (g), leaf dry weight (g); root fresh weight (g), root dry weight (g) and productivity (kg ha^{-1}).

For the coriander, parsley and garlic chives, the following characteristics were evaluated: plant height (cm), average number of tillers per plant stem, shoot fresh weight (g), shoot dry weight (g), root fresh weight (g), root dry weight (g) and productivity (kg ha^{-1}).

2.2 Biological efficiency of the system

Biological efficiency between the components of the intercropped systems was calculated using the land use efficiency index (LER), the relative contribution of the arugula crop to the LER (CRC), area time equivalent ratio (RAET) and system productivity index (IPS).

The LER assumes values of less than and greater than 1.0; if the LER>1, this indicates a productive advantage; LER = 1, no productive advantage, and if LER<1, then there is a productive disadvantage to the cropping system under study (Willey, 1979). To calculate the LER, the formula proposed by Willey (1979) was used.

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}} = I_a + I_b$$

where: Yab: is the production of crop “a” intercropped with crop“b”;

Yba: is the production of crop “b” intercropped with crop “a”;

Yaa: is the production of crop “a” in monoculture;

Ybb: is the production of crop “b” in monoculture; e,

I_a e I_b: specific productivities of individual cultures.

The CRC was calculated from the ratio between the individual relative leaf productivity (I) of the arugula and the total LER of the system, as per the formula proposed by Sousa and Macedo (2007):

$$CRC = \frac{(I \times 100)}{UET}$$, em que:

I - is the individual relative productivity;

UET - land use efficiency index.

To calculate the RAET, the methodology proposed by Hiebsch and McCollum (1987) was used:

$$RAET = \frac{(LER_a \times T_a) + (LER_b \times T_b)}{T_{ab}},$$

where: LER_a e LER_b: partial yield from efficient land use of intercropped crops;

T_a e T_b: number of days planted in harvesting crop 'a' and crop 'b';

T_{ab}: total time (days) of the intercropping system between cultures.

This index includes the time factor in calculating the efficiency of the intercropped system, where if the RAET>1, there is a productive advantage to the intercrop under evaluation; if RAET = 1, there is no productive advantage, and if RAET<1 there is a productive disadvantage, not justifying the intercropped system for the purposes of yield.

In general, when the period of the intercropped system is similar to the production cycle of the crops involved, the RAET remains equal to the LER; whereas when the period of the intercropped system is longer than the individual production cycle of the crops, the RAET is smaller than the LER, indicating the inefficient use of resources over time; when the period of the intercropped system is shorter than the production cycle of the crops, the RAET is greater than the LER, due to greater use efficiency of production factors over time, allowing more harvests during any one period.

The great advantage of the IPS is that it standardises the yield of the secondary crop relative to the main crop. The IPS was calculated as per the methodology of Odo (1991):

$$IPS = \left(\frac{Y_{bb}}{Y_{aa}}\right) x\ Y_{ab}+Y_{ba,}$$

where: Yab: is the production of crop "a" intercropped with crop"b";

Yba: is the production of crop "b" intercropped with crop "a";

Yaa: is the production of crop "a" in monoculture;

Ybb: is the production of crop "b" in monoculture; e,

I_a e I_b: specific productivities of individual cultures.

According to Chitarra and Chitarra (2005), a reduction of around 30% was estimated in the productivity of the secondary crops due to pre- and post-harvest losses, these new values for productivity being used to calculate the economic indicators and the biological efficiency of the companion crops.

2.3 Economic indicators

The economic analysis included the following: operational cost of production (OC; BRL ha^{-1}), gross revenue (GR; BRL ha^{-1}), gross profit (GP; BRL ha^{-1}), rate of return (RR; %) and profitability index (PI; %). Costs were assessed using the Conab methodology (CONAB, 2010), which considered actual disbursements (direct costs), from preparing the soil to harvesting, acquiring inputs, hiring labour and operating machinery.

The GR was obtained from the commercial production of the crops at the average price practiced in the region between October 2016 and January 2017. The arugula was marketed at BRL 6.00 per kg; the coriander and garlic chives at BRL 0.30 per pack of 100 g, and the parsley at BRL 0.60 per 100 g. For the arugula and coriander, which were grown in two cycles, the sum of the productivity of both cycles was used. In order to estimate the productivity of the crops, a working area of 7,700 m^2 was considered in each hectare, corresponding to the area actually cultivated. Gross profit (GP) considered the difference between the GR and OC. The RR was calculated from the ratio between the GR and OC, and the PI was obtained from the ratio between the GP and GR.

In addition to the agronomic aspects, the Area Equivalence Efficiency (AEE) was also evaluated: [(productivity of the main intercrop/productivity of the main single crop) + (productivity of the secondary intercrop/productivity of the secondary single crop)], as per Montesano and Peil (2006).

2.4 Statistical analysis

The results of the phytotechnical characteristics were submitted to analysis of variance (F-test), with the mean values compared by Tukey's test a level of 5% using the SSA software (SSA Institute, 2002). For the variables with two mean values (single crop and intercrop), the Kolmogorov test of normality was used, with the mean values compared by t-test (Satterthwaite method: inequality of variance) (PROC TTEST, SSA Institute 2002).

3. Results and Discussion

3.1 Phytotechnical variables

In the first cycle, there was a difference for plant height (PH), number of leaves (NL), and shoot fresh and dry weight (SFW and SDW) between the different intercropped combinations (Table 1). In the second cycle, the treatments differed for NL only. When comparing the two crop cycles, differences can be seen for each variable under analysis.

Table 1: Mean values for plant height (PH), root length (RL), number of leaves (NL), and shoot fresh and dry weight (SFW and SDW), in arugula grown as a single crop (T1) and intercropped (T2, T3 and T4) with aromatic condiment plants. [1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives. Means followed by the same lowercase letter in the column and uppercase in the row do not differ, by the "t" test, at 5% probability.

Treat.	PH		RL		NL		SFW		SDW	
	cm						g			
	1°Cycle	2°Cycle	1°Cycle	2°Cycle	1°Cycle	2°Cycle	1°Cycle	2°Cycle	1°Cycle	2°Cycle
T1	3.37abA	2.12 aB	22,2aA	9,16aB	16bA	19,6bA	43,03bA	59,00aA	4,10cB	6.44aA
T2	3.95aA	2.06aB	21,71aA	13,22aB	20,2abA	17,5bA	119,75aA	51,30aB	8,37aA	6.48aB
T3	4.46aA	2.61aB	23,62aA	11,80aB	21,4aB	25,7aA	81,00aA	71,00aA	8,73aA	6.90aB
T4	2.65bA	2.15aB	22,26aA	12,08aB	19,1abA	17,1bA	87,75aA	92,5aA	6,41bA	6.17aA

Source: Authors.

In the first cycle, the arugula plants with the best agronomic performance were those intercropped with coriander and parsley, showing the highest mean value for each variable under analysis. When intercropped with garlic chives, the plants showed similar values to the single crops for height, root length and number of leaves, however, they showed higher values than the single crop for shoot fresh and dry weight. In the second crop cycle, only the number of leaves differed, with the plants intercropped with parsley having the greatest number of leaves.

The difference in results between crop cycles suggest that during the second cycle there was less competition by the arugula between treatments, as the cycles showed similar mean values between the different combinations. As such, it can be seen that the arugula plants showed different behaviour during each crop cycle. This behaviour appears to have been due to climate variations during the experiment. Factors such as relative humidity and rainfall differed more significantly between the cycles of arugula and coriander. The first cycle occurred in the dry season, when the relative humidity was 61% on average, and the accumulated rainfall was only 4.45 mm. During the second cycle, the average relative humidity was 71.5%, and the accumulated rainfall was much higher, at 111.75 mm. According to Trevisoli *et al*. (2017), arugula is a crop both sensitive and responsive to climate.

With the most favourable climate conditions during the first cycle, the arugula plants gave better results for height and root length in all treatments, i.e. they had the largest plants, which can be explained by greater occupation of the area culminating in increased competition between the plants, and may have contributed to the growth in height in the search for light, and the growth in roots in the search for available water and nutrients in the soil solution (TAIZ *et al*., 2017).

During the second crop cycle, the plants displayed less height and root length, however, the fresh and dry weight remained similar to that of the first cycle, except for plants intercropped with coriander, which had more than twice the weight of the first cycle. One possible explanation for the plants having similar fresh and dry weight in both cycles is that despite being smaller, the plants did not have to compete for water and nutrients with their companion crops, which may have contributed to the weight increase in their tissue. This situation may also have favoured the greater weight seen in the coriander plants grown during the second cycle compared to the first.

Another factor that may have caused a reduction in some of the responses during the second cycle was the greater rainfall. Purquerio *et al*. (2007) points out that the production of arugula is affected during seasons with greater rainfall (summer). According to that researcher, this is due to the impact of raindrops on the leaves, as well as the movement of soil particles that damage the leaves, and ends up by promoting a certain delay in plant development, in addition to reducing the end quality of the product. Similar inferences were made by Cunha *et al*. (2013), who saw greater production during the dry season in arugula grown under irrigation in the northeast of the state of Mato Grosso do Sul. As such, intercropping arugula may represent a greater guarantee of return to the producer since diversifying crops reduces the risk of loss under unfavourable climate conditions.

From the results of the single and intercropped aromatic condiment species evaluated in this study, the single crops showed the better performance (Table 2). These results may have been due to the combination of two factors. First, under the intercropped systems, the crops were introduced at almost the same time, which may have generated greater competition due to the varietal differences of each species, and which did not occur in the single crops. Second, the development and establishment of the arugula crop in the production area was faster and covered a larger area, which also did not occur in the single crops of the aromatic condiment species. These factors together may have resulted in greater competitive capacity in the arugula at the expense of the aromatic condiment species.

Table 2: Mean values for plant height (PH), root length (RL), number of stems/tillers (STM/TIL), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW) and root dry weight (RDW), in the companion crops under single and intercropped systems. [1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives. Means followed by the same letters in column do not differ by Tukey test at 5% probability.

	Parsley						
Treatament	PH	RL	STM	SFW	SDW	RFW	RDW
	cm			g			
Intercropped	29,3^{ns}	12,6 b	6,2^{ns}	486,1 b	33,9 b	76,5 b	13,2 b
Single	29,5	17,6 a	7,3	604,8 a	54,4 a	113,5 a	24,1 a
C.V. (%)	**9,28**	**19,73**	**13,22**	**23,48**	**34,59**	**26,62**	**32.21**
	Garlic chives						
Treatament	PH	RL	TIL	SFW	SDW	RFW	RDW
	cm			g			
Intercropped	35,75 ^{ns}	25,87^{ns}	2,2 ^{ns}	403,5 ^{ns}	33,62 b	63,0^{ns}	9,9 ^{ns}
Single	34,97	27,68	2,9	481,0	50,67 a	67,3	10,3
C.V. (%)	**6,87**	**11,66**	**20,98**	**22,41**	**30,69**	**12,91**	**17,97**
	Coriander **1° Cycle**						
Treatament	PH	RL	STM	SFW	SDW	RFW	RDW
	cm			g			
Intercropped	12,23^{ns}	8,46^{ns}	3,9^{ns}	226,00 b	21,61 b	34,5^{ns}	4,32^{ns}
Single	12,11	9,51	4.2	334,8 a	31,63 a	38,5	6,45
C.V. (%)	**15,01**	**9,14**	**8,29**	**23,39**	**25,07**	**35,72**	**38,32**
	Coriander **2° Cycle**						
Treatament	PH	RL	STM	SFW	SDW	RFW	RDW
	cm			g			
Intercropped	9,66^{ns}	10,77^{ns}	4^{ns}	273,5^{ns}	26,81 a	32,5^{ns}	8,10 a
Single	9,45	10,15	3,6	269,5	16,52 b	29,0	4,62 b
C.V. (%)	**13,18**	**9,47**	**11,27**	**14,23**	**58,89**	**40,53**	**64,60**

Source: Authors.

During the second cycle, shoot and root dry weight in the coriander was found to be greater in the intercropped plants. This may have been due to less interference from the arugula plants on the coriander. During this cycle, the smaller size of the arugula plants, probably caused by questions of climate, such as greater rainfall and less incident light, resulted in less competition for production factors in the coriander plants. Smaller plants have a smaller leaf area, thereby offering far less shading to plants that are closer and underneath their structures.

3.2 Biological efficiency of the system

Biological efficiency, demonstrated by land use efficiency via the land equivalent ratio (LER) (Table 3), shows that each intercropped system presented a value greater than the base value of 1.0 (the value that represents a balance in the competitive process of the intercropped system). This demonstrates the effect of cooperation or compensation between the intercropped species evaluated in this study, with advantages to the intercropped system (Barros Junior, 2020). The results found in this work are similar to those seen by Cecílio Filho *et al*. (2008a), who evaluated the productive and economic viability of an intercropped system of chicory and arugula based on the time of crop establishment, and also found that all intercropped and evaluated treatments prove to be viable from the point of view of the LER.

Table 3: Land equivalent ratio (LER), relative contribution of the arugula crop to the LER (CRC), area time equivalent ratio (RAET) and system productivity index (IPS), in arugula, coriander, parsley and garlic chives grown as single crops and intercrops. [1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives.

Treatament[1]	LER	CRC	RAET	IPS
		%	kg/ha^{-1}	kg/ha^{-1}
T1	1	-	-	-
T2	1,6	31,44	1,03	57.471,2
T3	1,3	68,99	1,24	23.751,6
T4	1,4	62,72	1,28	10.038,4
T5	1	-	-	-
T6	1	-	-	-
T7	1	-	-	-

Source: Authors.

In this study, the highest value seen for the LER was in T2 (1.6), followed by T4 and T3 with values very close to 1.4 and 1.3 respectively. Hendges *et al.* (2019), evaluating an intercrop of kale with the Apiaceae, coriander and parsley, also used in the intercrops grown in this study and under similar growing conditions, found that crops of this family afforded the highest values for LER, indicating greater biological efficiency. This result shows that the intercropped system favoured growth and production in the vegetables, which means that the combinations used were viable (Ribas *et al*., 2020).

The relative contribution of the arugula (CRC) to forming the LER in each intercropped system was 31.44% in the system with coriander, 68.99% with parsley and 62.72% with garlic chives. The results suggest that the smaller contribution of arugula when intercropped with coriander is due to the high yield of the coriander (in two cycles), compared to other companion crops.

For the area time equivalent ratio (RAET), considered another way of assessing the efficiency of intercrops, and that takes into account the time the plants used in the intercropped system spend in the field from planting to harvest, made it possible to obtain values greater than 1.0 in each intercropped treatment T2 (1.03), T3 (1.24) and T4 (1.28), i.e. they all presented a greater productive advantage in relation to the single crop (Manasa *et al*., 2020).

In this case, the RAET shows that the duration of the intercrop was shorter than the total productive cycle of the arugula, which was considered the main crop, with the coriander harvested 30 days after sowing in each cycle, giving a total of 60 days growth (due to the two production cycles), with 65 days for the parsley and 65 days for the garlic chives intercropped with the arugula that remained a total of 70 days in the field, considering both cycles. As such, the RAET predicts that higher values show greater agricultural efficiency, as was highlighted in T2, T3 and T4.

With the production stability of the intercropped systems under study, represented by the system productivity index (IPS), which standardises the productivity of the companion (secondary) crops based on the main or primary crop (arugula), it was found that the productivity of the coriander, parsley and garlic chives intercropped with the arugula is higher than their productivity as single crops, i.e. the IPS of the companion crops in the intercrop were 33%, 22% and 8% higher respectively than their single crops, which can be explained by the combinations promoting better and more effective use of resources in the companions than when grown as a single crop (Islam *et al*., 2018).

3.3 Economic indicators

For the producer, the most important thing in the cropping system is the financial return obtained with the yields (Trupti *et al*., 2018). The results show that the yields of the single crops were higher than those seen in the intercrops. However, the financial return of an intercropped system represents the combined productivity of the intercropped species; when the combined productivity for each intercropped system is evaluated, greater yields are seen than in the respective single crops.

Table 4: Gross Revenue (GR), Operational Cost of Production (OC), Gross Profit (GP), Rate of Return (RR), Profitability Index (PI), Monetary Advantage (MA) and Productivity in the arugula, coriander, parsley and garlic chives grown as single crops and intercrops. Fortaleza, Ceará, UFC, 2017. [1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives. Arugula in intercrops [(A)]; coriander in intercrops [(C)]; parsley in intercrops [(P)]; garlic chives in intercrops [(G)].

Treat.[1]	GR	OC	GP	RR	PI	MA	Productivity
		R$/ ha^{-1}			%	R$/ ha^{-1}	Kg/ha^{-1}/time
T1	58.922,34	9.200,00	49.722,34	6,40	0,84		19.639,81
T2	88.114,97	9.850,00	78.264,97	8,95	0,89	33.043,11	9.878,14[(A)] 19.230,75[(C)]
T3	75.125,82	10.501,79	64.624,03	7,15	0,86	17.147,95	17.556,00[(A)] 7.485,94[(P)]
T4	63.877,29	9.942,00	53.935,29	6,42	0,84	16.567,03	16.632,00[(A)] 4.660,43[(G)]
T5	58.163,88	6.048,30	52.115,58	9,62	0,90		38.775,92
T6	55.883,52	5.655,51	50.228,01	9,88	0,90		18.627,84
T7	27.777,75	4.955,57	22.822,18	5,61	0,82		9.259,25

Source: Authors.

For gross revenue, represented by the total sales value of the products, the single arugula (T1) gave an income of BRL 58,922.34 per hectare, lower than the revenue from the intercropped systems. The single crops of coriander, parsley and garlic chives also had lower values for GR compared to their respective intercropped systems.

The results of the economic indices show the agronomic and biological superiority of the intercrops in relation to the single crops, possibly due to better efficiency in the use of environmental resources and inputs. Another important observation is the arugula cultivar used in this study (cultivated), which appears to show better agronomic and biological efficiency under intercropped systems (Linhares *et al*., 2017).

The intercropped system with the highest gross revenue, BRL 88,114.97 per hectare, was made up of arugula and coriander (T2). This intercropped system is interesting, as both crops have similar cycles, and can be harvested at almost the same time, planning for a more efficient use of labour in this type of cultivation.

Although production costs in the intercropped systems were higher than those required for installing the single crops, it could be seen that Gross Profit (GP) was also higher, which makes the intercropped system economically compensatory for the producer.

The T2 treatment gave the best results for economic return, with a gross profit of BRL 78,264.97 per hectare, at a rate of return of 8.95 and a profitability index of 89%. These results indicate that for every BRL 1.00 invested, BRL 8.95 was generated, i.e. the financial gains pay for the costs incurred with the cultivation, and still give an additional return of 89% in relation to net revenue. Among the economic indicators under evaluation, profit is the one indicator that allows the producer to visualise the best intercropped system in terms of agroeconomic efficiency (Silva *et al*., 2019).

Another intercropped system that afforded excellent economic return was the arugula with parsley (T3). In this intercropped system, a gross profit of BRL 64,624.03 per hectare was obtained, at a rate of return of 0.86 and a profitability index of 86%. In this intercropped system, two cycles of arugula and one cycle of parsley were produced.

For T4, arugula intercropped with garlic chives, which showed a gross profit of BRL 53,935.29, high values were also seen for the rate of return (7.15) and profitability index (84%). This intercropped system has an important advantage, where the garlic chives, in relation to the other aromatic condiment crops under study, can be harvested several times without the need for additional spending on further planting, since its production system in the form of regrowth, allows the product to be harvested with no damage to the plants that remain in the field.

In addition to gross profit, the monetary advantage, which represents how much additional revenue is collected with the intercropped systems compared to the single systems, shows that all the intercropped treatments, T2 (BRL 33,043.11), T3 (BRL 17,147.95) and T4 (BRL 16,567.03) were economically viable.

Each of the intercropped systems showed a higher value than the base value of 1.0 (the value that represents a balance in the competitive process of the intercropped system): T2 (1.2), T3 (1.3) and T4 (1.35). Such results show advantages for the intercropped system. For the single arugula to have a yield equal to that of the intercropped systems in T2, T3 and T4, it would be necessary to increase the area cultivated as a single crop by 48%, 28% and 2% respectively.

Hendges *et al*. (2019), evaluating an intercrop of kale with the Apiaceae (coriander and parsley) used in this study and under similar growing conditions, found that crops of this family gave the highest values for the AEE, indicating greater biological efficiency. Apiaceae are known to be important crops when intercropped with other vegetables, where the better results seen under intercropped systems are due to crop diversification, which, in addition to agronomic benefits, allows a complement to marketing, affording greater financial returns (Sousa *et al*., 2018; Brito, 2018; Akshatha *et al*., 2019).

4. Conclusion

Arugula intercropped with coriander showed greater combined productivity, greater biological efficiency and better economic returns, compared to the other combinations.

Arugula intercropped with parsley showed values similar to the intercropped system with coriander, and may be a viable production alternative in areas where parsley is consumed more than coriander.

The intercropped system with garlic chives can be considered a viable production alternative since it presented more attractive values than did the single arugula.

In general, we show that the intercropping gives greater total yields and better area use efficiency in space and time. In addition, we show a complete research that addresses this from specific indicators and indices that can be used in intercropping systems to assist in choosing companion species and the most advantageous systems.

We suggest for future research that, in addition to different species, different varieties may also be studied that may have different characteristics and respond differently to the intercropping. We also suggest plantations with similar densities in monocultures and in a intercropping to optimize the area with increased production.

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