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Successive vegetable intercropping in organic system: agronomic and economic performance

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ABSTRACT

Intercropping is a technique employed to increase productivity and profit per unit area in addition to maximizing the use of environmental resources and promoting ecological balance. Considering the advantages this practice can offer in vegetable cultivation, the present study aimed to evaluate the agronomic indices and profitability achieved through the cultivation of common kale intercropped with carrots and mustard in a crop succession system. The experiment was conducted using a randomized block design (RBD), with four replicates. The kale plots were arranged in a factorial scheme (2x2), considering: factor spacing for kale planting [E_1 (1.00 x 0.50 m) and E_2 (0.50 x 0.50 m)]; and the intercropping factor [presence and absence of intercropping (considering carrots first and then mustard)]. The carrot and mustard plots followed the RBD, with three cultivation systems (treatments): system 1 = monoculture; system 2 = intercropping with kale at E_1; system 3 = intercropping with kale at E_2. Throughout the kale cycle, carrots were replaced by mustard. The kale-carrot intercropping, succeeded by kale-mustard at the E_1 spacing, showed good yield and land use efficiency of 184%, with greater profitability than monocultures. The kale-carrot intercropping, succeeded by kale-mustard at the E_2 spacing, also showed agronomic efficiency (63%) and positive economic yield, but with lower profitability than monocultures.

Keywords: *Brassica oleracea* var. *acephala*, *Brassica juncea*, *Daucus carota*, diversification, horticulture, vegetables, profitability.

RESUMO

Consórcios sucessivos de hortaliças em sistema orgânico: desempenho agronômico e econômico

A associação de culturas é a técnica empregada para aumentar a produtividade e lucro por unidade de área, além de possibilitar a maximização da utilização de recursos ambientais e promover equilíbrio ecológico. Considerando as vantagens que esta prática pode oferecer no cultivo de hortaliças, o presente trabalho objetivou avaliar os índices agronômicos e a rentabilidade alcançados com cultivo de couve comum, consorciada com cenoura e mostarda, em um sistema de sucessão de culturas. O experimento seguiu o delineamento em blocos casualizados (DBC), com quatro repetições. As parcelas com couve foram organizadas em esquema fatorial (2x2), considerando: fator espaçamento para plantio de couve [E_1 (1,00 x 0,50 m) e E_2 (0,50 x 0,50 m)]; e o fator consórcio [presença e ausência do consórcio (considerando com cenoura e depois com mostarda)]. As parcelas de cenoura e mostarda, seguiram o DBC, sendo os três sistemas de cultivo (tratamentos): sistema 1 = monocultivo; sistema 2 = consórcios com a couve no E1; sistema 3 = consórcios com a couve no E2. Ao longo do ciclo da couve a cenoura foi substituída pela mostarda. O cultivo consorciado de couve-cenoura, sucedido por couve-mostarda, no espaçamento E1, apresentou bom rendimento e eficiência no uso da área na ordem de 184%, com maior lucratividade que os monocultivos. O cultivo consorciado de couve-cenoura, sucedido por couve-mostarda, no espaçamento E2, também apresentou eficiência agronômica (63%) e rendimento econômico positivo, porém, com menor lucratividade que os monocultivos.

Palavras-chave: *Brassica oleracea* var. *acephala*, *Brassica juncea*, *Daucus carota*, diversificação, olericultura, hortaliças, rentabilidade.

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Crop association has been one of the strategies for increasing productivity and profit per unit area (Bezerra Neto *et al*., 2001), in addition to maximizing the use of environmental resources, improving the management of pests, diseases, and weeds, reducing the use of chemical inputs, and promoting ecological balance.

One association technique is the use of intercropping, which is particularly important in organic farming systems, allowing two or more species to be cultivated simultaneously in the same area, coexisting for at least part of their production cycles (Cecílio Filho *et al*., 2015). In addition to the benefits previously mentioned, intercropping also contributes to the stabilization of rural activities by ensuring staggered harvests (Montezano & Peil, 2006), soil cover and protection, efficient use of labor, greater biological diversification, among others (Cardoso *et al*., 2017).

The advantages offered by this practice can be well-utilized in as this vegetable cultivation, agricultural sector is characterized by intensive management and soil exposure, challenges in weed control, intensive use of pesticides, fertilizers, and irrigation, among other cultural practices that cause considerable environmental impacts (Cecílio Filho *et al*., 2003).

The intensive practice of vegetable cultivation requires knowledge of the crops and techniques that can be applied to ensure a return on the investments made by the producer (Brito *et al*., 2017). Therefore, the efficiency of intercropping systems is based on the complementarity between the crops and the most ideal intercropping design possible concerning the use of productive resources, as well as reducing the negative effects of one crop on the other, to maximize economic yield (Cecílio Filho *et al*., 2017).

Complementarity is related to the growth patterns of the species, so that they differ in time and space, minimizing interspecific competition for environmental resources (water, light, and nutrients) and possible allelopathic effects, while optimizing productive indices, rapid maturation, biological efficiency, and high biomass productivity (Cecílio Filho *et al*., 2017), leading to balanced species growth and consequently positively characterizing intercropping systems (Albuquerque *et al*., 2012).

Several studies demonstrate the improvement of agronomic performance in intercropped cultures compared to those cultivated in monoculture (Oliveira *et al*., 2005; Massad *et al*., 2010). Furthermore, the biological interactions occurring in these systems represent ecological services of significant importance, compared to monoculture, provided by the "companion" plant (secondary crop) (Montezano & Peil, 2006).

Thus, the objective was to evaluate the agronomic indices and profitability achieved through the cultivation of common kale intercropped with carrots and mustard in a crop succession system.

MATERIAL AND METHODS

The experiment was conducted in the experimental area of the Federal Institute of Education, Science, and Technology of Espírito Santo (IFES), Campus Alegre-ES, located at an altitude of 120 meters, on a medium-textured Red-Yellow Latosol (Santos *et al*., 2018). According to Köppen's classification, the region's climate is Awa, tropical hot and humid, with a cold and dry winter, an average temperature of 26ºC, and an average annual precipitation of 1.250 mm (Lima *et al*., 2008). During the experiment, from April to September 2020, maximum temperatures ranged between 26.5 and 35.1°C, and minimum temperatures between 14.9 and 21.2°C. The accumulated precipitation was 850 mm (INMET, Alegre-ES).

Soil samples were collected from the 0-20 cm depth layer and, after analysis, the following characteristics were observed: pH (H2O)= 5; Mehlich 1 phosphorus (P)= 39.80 mg/dm^3; potassium (K)= 69 mg/dm^3; aluminum (Al): 0.0 cmol$_c$/dm^3; hydrogen + aluminum (H + Al)= 1.80 cmol$_c$/dm^3; calcium (Ca)= 1.35 cmol$_c$/dm^3; magnesium (Mg)= 0.49 cmol$_c$/dm^3; sum of bases (SB)= 1.97 cmol$_c$/dm^3; V%= 52.25; cation exchange capacity (CEC$_{7,0}$)= 3.77 and organic matter (OM)= 14 g/kg. Soil preparation was through harrowing.

Planting fertilization was performed as follows: 20 t/ha of aged organic compost, distributed on the bed surface; topdressing: application of 5 kg/m² of the bed with organic compost, 30 and 45 days after transplanting the kale. Biofertilizer sprays were also applied at a 0.1% concentration to improve micronutrient supply. These were also applied to carrots and mustard (30 and 45 days after their transplanting).

The chemical analysis of the organic compost revealed the following composition: 20.30 g/kg of N; 3.40 g/kg of P; 6.0 g/kg of K; 12.30 g/kg of Ca; 4.40 g/kg of Mg; 2.60 g/kg of S; 6.06 mg/kg of B; 55.90 mg/kg of Zn; 307.45 mg/kg of Mn; 1770 mg/kg of Fe and 16.55 mg/kg of Cu. The chemical composition of the biofertilizer was: 70 g/L of N; 112 g/L of P_2O_5; 112 g/L of K_2O; 14 g/L of Ca; 7 g/L of Mg; 7 g/L of B; 1.4 g/L of Co; 2.8 g/L of Cu; 1.4 g/L of Fe; 7 g/L of Mn; 1.4 g/L of Mo; 14 g/L of Zn and 84 g/L of TOC (Total Organic Carbon).

Common kale (cultivar Manteiga) was cultivated in two different spacings (Figure 1), intercropping first with carrots and, after their harvest, with mustard. Thus, in both spacings, intercropping of kale-carrot, followed by kale-mustard, was performed, aiming to optimize the use of production resources. Common kale (*Brassica oleracea* var. *acephala*) is an interesting vegetable for these successive intercrops, as it has a productive cycle that can reach 8 months (Trani *et al*., 2015).

Kale seedlings (cultivar Manteiga) were obtained by sowing in 200-cell polystyrene trays containing commercial substrate and transplanted with four to five developed leaves. After transplanting, direct seeding of carrot (cultivar Brasília) was carried out by broadcasting, in four planting rows, along the length of the bed, spaced 25 cm apart, totaling 400,000 plants/ha. Plantlets were thinned at 21 days after sowing, maintaining around 20 plants per linear meter, spacing maintained in all carrot plots (Figure 1).

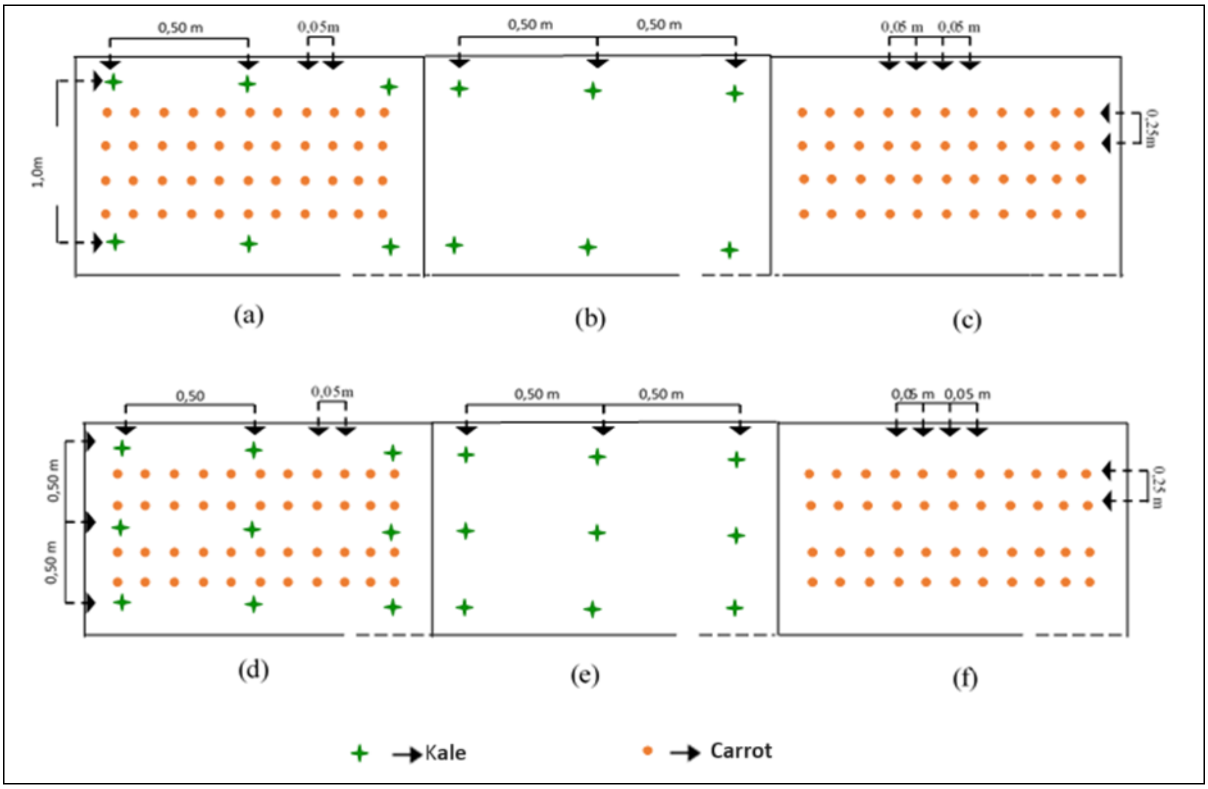

Figure 1. Diagrammatic representation of the treatments according to their respective layouts in 1.2 m wide beds. (a)= kale intercropping at spacing E_1 (1.00 x 0.50 m) with carrots; (b)= kale monoculture at spacing E_1; (c)= carrot monoculture at spacing 0.25 x 0.05 m; (d)= kale intercropping at spacing E_2 (0.50 x 0.50 m) with carrots; (e)= kale monoculture at spacing E_2 (0.50 x 0.50 m); (f)= carrot monoculture at spacing 0.25 x 0.05 m. Alegre, UFES, 2020.

After the carrot harvest (carried out 100 days after sowing), the mustard seedlings were transplanted. Mustard seedlings (Smooth type) were obtained after sowing in 200-cell polystyrene trays containing commercial substrate, and transplanted when they had four to five developed leaves, at 0.30 x 0.30 m spacing; this spacing was maintained in all mustard plots (Figure 2). Each experimental unit was represented by a plot of 3.0 x 1.2 m, being the entire plot considered the useful area. Mustard (*Brassica juncea*) is a vegetable that adapts well to a successive intercrop, aiming for a quick harvest, as it is harvested 45 to 50 days after sowing (Filgueira, 2008).

Beds were irrigated daily, by sprinkling, in the morning, up to near the soil's field capacity, except on rainy days. Cultural practices consisted of weed control through mechanical weeding and spraying with alternative solutions [bovine milk whey (5%), with wood ash (10 g/liter)] (Penteado, 2007) when aphids were present.

The following evaluations were carried out on the kale: number of leaves/plant, average fresh weight of leaves, yield of harvested leaves during each intercrop (t/ha); carrot: average fresh weight of roots, root size (length and diameter, at the midpoint), root yield (t/ha); mustard: number of leaves, average leaf weight, and yield (t/ha), calculated by the weight of the plant harvested with a 60-day cycle.

After obtaining all the data of each treatment, the following parameters were calculated: Relative Crops Contribution (RCC). The Land Use Efficiency Index (LUEI), in each intercrop (kale + carrot and kale + mustard), was calculated using the formula (Vandermeer, 1990):

$$LUEI = IA + IB$$

Where: IA and IB are the individual relative productivity indices of crops A and B studied in the intercropping. The values for "I" are calculated using the formula:

$$I = Yinter/Ymono$$

Where: Yinter = are the yields of the crops in intercropping; Ymono = yields in monocultures.

The Relative Crops Contribution (RCC) to the Land Use Efficiency Index (LUEI) is derived from the ratio between the Individual Relative Productivity and the total LUEI of the system, indicating the percentage contribution of each crop to the total index. The RCC values for each crop were calculated using the formula:

$$RCC = (I/LUEI) \times 100$$

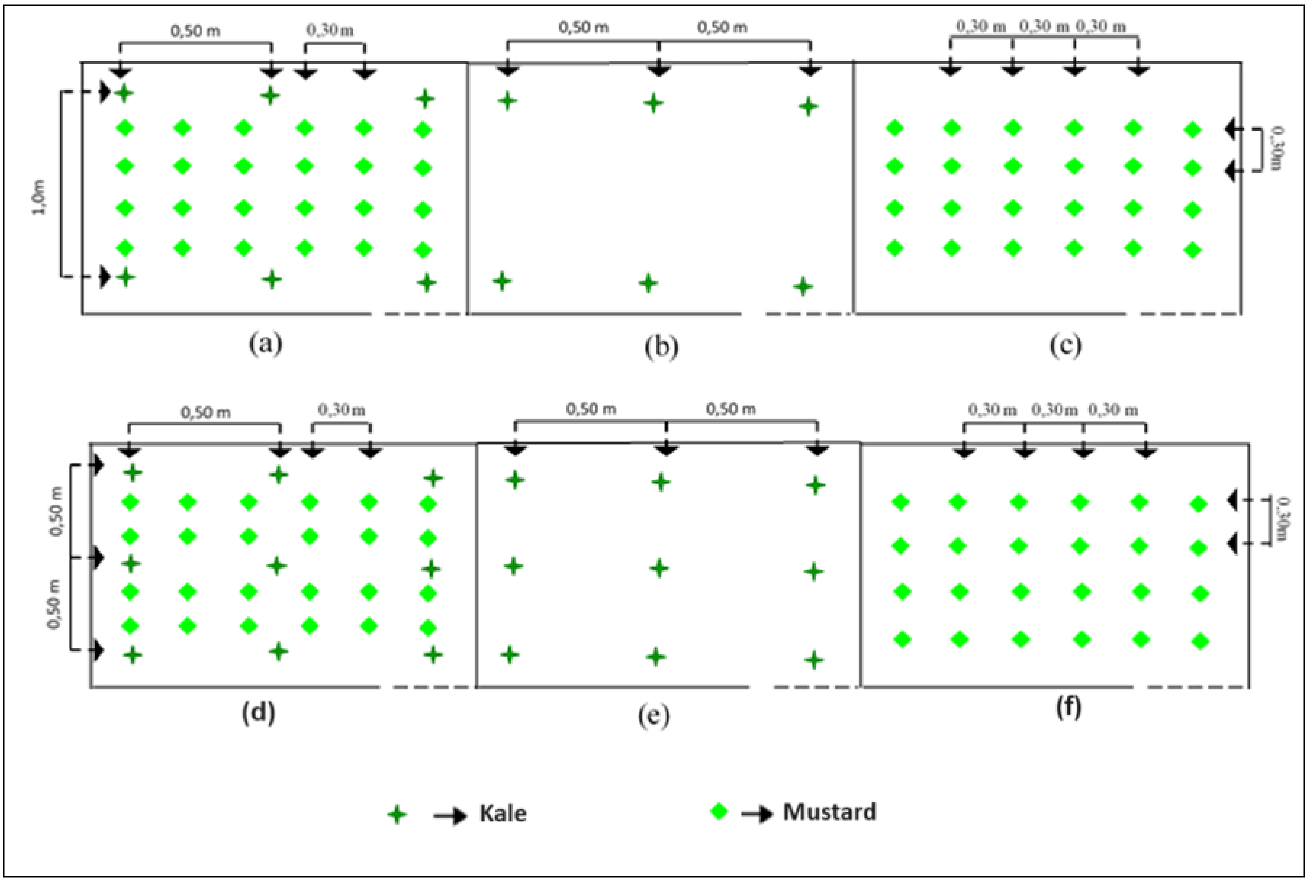

Figure 2. Diagrammatic representation of the treatments according to their respective layouts in 1.2 m wide beds. (a)= kale intercropping at spacing E_1 (1.00 x 0.50 m) with mustard; (b)= kale monoculture at spacing E_1; (c)= mustard monoculture at spacing 0.30 x 0.30 m; (d)= kale intercropping at spacing E_2 (0.50 x 0.50 m) with mustard; (e)= kale monoculture at spacing E_2 (0.50 x 0.50 m); (f)= mustard monoculture at spacing 0.30 x 0.30 m. Alegre, UFES, 2020.

The effective operational cost (EOC), which involves expenses for labor, machinery/equipment operations, and materials consumed during the cultivation cycle, and the total operational cost (TOC), which in this study is the EOC plus only the social security contribution (2.3% on gross income) (Carvalho *et al*., 2021), were estimated for each production system, as presented in Table 1.

Profitability indicators were calculated, such as Gross Income (GI), which is the expected revenue for a given production per hectare. It was calculated using the formula:

$$GI = Cp \times Pu$$

Where: Cp = crop production per unit area; Pu = price per unit of the crop. Note: For the calculations in this study, the prices paid to producers at the Supply Centers of Espírito Santo (Ceasa-ES) were considered, based on Brazilian Reais (R$), on September/2023: R$ 3.35/kg for kale, R$ 2.00/kg for carrots, and R$ 2.20/kg for mustard.

Operational Profit (OP) was also calculated: the difference between gross income (GI) and operational cost per hectare (TOC) (OP = GI – TOC); Benefit/Cost Ratio (BCR): the ratio between gross income and operational cost (BCR = GI/TOC).

The experiment followed a randomized block design (RBD) with four replicates. The kale data were organized in a factorial scheme (2x2), considering: planting spacing factor: E_1 (1.00 x 0.50 m) and E_2 (0.50 x 0.50 m); and intercropping factor: presence and absence of intercropping (considering carrots first and then mustard). This resulted in four cultivation systems (treatments) for the two analyses of variance (both with carrots and mustard).

For the variance analysis of the carrot and mustard data, only the RBD was considered, with three cultivation systems (treatments): system 1 = monoculture; system 2 = intercropping with kale in E_1; system 3 = intercropping with kale in E_2.

The data were subjected to variance analysis using an F-test at $p<0.05$ probability, and for the variables that showed significant differences, Tukey's test at $p<0.05$ was applied for mean comparison. Statistical analyses were performed using the Rbio statistical program (Bhering, 2017).

RESULTS AND DISCUSSION

Regarding the kale and carrot intercropping, we observed that there were interactive effects between the adopted spacing and the cultivation system (intercropped or monoculture) on the performance of kale.

Table 1. Effective and total operational cost (U$/ha) for production in one hectare under monoculture and intercropping systems, considering in the intercropping the arrangement of kale with carrot and the succession with mustard. Alegre, UFES, 2020.

Items	Kale monocult. E_1	Kale monocult. E_2	[2]Ka E_1 x Ca	[2]Ka E_2 x Ca	Carrot monocult.	[3]Ka E_1 x Mu	[3]Ka E_2 x Mu	Mustard monocult.
Inputs	**Operational cost (U$/ha)[1]**							
Seeds	12.45	24.90	448.02	460.47	435.57	32.30	32.30	32.30
Seedling formation								
Tray preparation	21.78	43.56	21.78	43.56	-	49.82	49.82	49.82
Sowing	21.78	43.56	21.78	43.56	-	49.82	49.82	49.82
Seedlings irrigation	8.17	8.17	8.17	8.17		8.17	8.17	8.17
Soil preparation								
Land cleaning	21.78	21.78	21.78	21.78	21.78			
Plowing + harrowing and bedding	89.84	89.84	89.84	89.84	89.84			
Early cultural practices								
Seedlings transplant/carrot sowing and thining	21.78	43.56	399.88	421.66	378.10	49.82	49.82	49.82
Planting fertilization	164.79	164.79	164.79	164.79	164.79			
Maintenance cultural practices								
Top dressing[5]	113.43	113.43	113.43	113.43	113.43			
Biofertilizers	80.07	80.07	80.07	80.07	80.07	80.07	80.07	80.07
Irrigation[6]	99.36	99.36	99.36	99.36	115.70	106.17	106.17	85.75
Other cleaning and crop maintenance	163.34	266.90	163.34	266.90	177.93	88.96	111.00	88.96
Harvest								
Harvest and post-harverst	196.01	392.01	1.720.51	1916.51	1.524.50	284.97	480.97	88.96
[4]EOC	**1014.58**	**1391.93**	**3352.75**	**3269.63**	**3101.71**	**750.10**	**935.84**	**533.67**
Tax charges								
Social contribution (2.3% of gross income)	296.98	946.89	514.66	378.93	205.66	133.08	161.74	36.09
[4]TOC	**1311.56**	**2338.82**	**3867.41**	**3648.56**	**3307.37**	**883.18**	**1097.58**	**569.76**

Value based on the exchange rate of the dollar in the Brazilian market (R$5.12/US$1.00), in September 2023. [2]Ka E_1 x Ca – Kale intercropping (spacing 1) x carrot; Ka E_2 x Ca – Kale intercropping (spacing 2) x carrot. [3]Ka E_1 x Mu – Kale intercropping (spacing 1) x mustard; Ka E_2 x Mu – Kale intercropping (spacing 2) x mustard. [4]EOC – Effective operational cost; TOC - Total operational cost. [5]Calculation based on the main crop. cabbage; [6]Calculation based on the requirements (ETP) of the main crop. kale. except in monocultures of carrot and mustard.

Comparing the cultivation systems in spacing E_1, it is possible to affirm that there is no difference in the agronomic performance of kale (number, average weight, and leaf yield), whether in monoculture or intercropped with carrots (Table 2). However, adopting spacing E_2, we observed that there was a decrease in the number, average weight, and leaf yield of kale in the intercropped system. This suggests that in an intercropping system with carrots, denser kale spacing may negatively impact kale production (Table 2).

The productive variables of carrots (average fresh weight, root length and diameter, and total yield) did not show significant statistical differences concerning the adopted cultivation systems. However, a higher percentage of marketable roots was produced in the intercropped systems, with a greater percentage when carrots were intercropped with kale in spacing E_2 compared to spacing E_1 (Table 3).

Table 2. Number, average weight and productivity of kale leaves cultivated in two spacings, either in monoculture or intercropped with carrot under organic management. Alegre, UFES, 2020.

	Leaves number/plant		**Leaves average weight (g)**		**Productivty (t/ha)**	
	Monoculture	**Intercropping**	**Monoculture**	**Intercropping**	**Monoculture**	**Intercropping**
E_1[2]	47.50 a[1]	44.75 a	15.56 a	16.55 a	15.13 a	14.16 a
E_2[2]	54.51 a	21.75 b	24.76 a	12.13 b	48.24 a	10.32 b
CV[3]	39.53		32.54		37.56	

[1]Means followed by the same letter did not differ from each other statistically by the Tukey's test ($p<0.05$). [2]Spacing E_1 (1.00 x 0.50 m); Spacing E_2 (0.50 x 0.50 m); [3]CV= Coefficient of variation (%)

Table 3. Percentage of marketable roots and total productivity of carrots intercropped with kale in two spacings under organic management. Alegre, UFES, 2020.

Crop system	**Marketable roots (%)**	**Total productivity (t/ha)**
Carrot monoculture	63.2[1]	17.55 a
Kale intercropping (E_1[2])	72.2	20.20 a
Kale intercroppin (E_2[2])	91.2	15.05 a
CV[3]	--	31.61

[1]Means followed by the same letter did not differ from each other statistically by the Tukey's test ($p<0.05$). [2]Spacing E_1 (1.00 x 0.50 m); Spacing E_2 (0.50 x 0.50 m); [3]CV= Coefficient of variation (%).

This result suggests that this system could provide benefits to carrots, such as creating a favorable microclimate or offering some protection, resulting in a higher number of roots meeting commercial standards.

The results indicate that the success of the kale and carrot intercropping depends on the correct adoption of spacing, as less dense kale planting likely allows the crops to exploit different niches, especially related to growth habits that occur at different levels. Therefore, even when associated, competition is avoided.

When focusing on crop succession, kale, with a longer cycle, was followed by mustard as a companion crop after the carrot harvest, and no adverse effects were observed in the production of either crop.

The leaf yield of kale in monoculture, during the concomitant period with mustard intercropping, in spacing E_1 was 6.78 t/ha, and in spacing E_2 was 8.24 t/ha. These did not differ from the yields obtained with kale in intercropped areas in spacing E_1 (4.48 t/ha) or spacing E_2 (6.25 t/ha). Since kale was already established in the area when mustard was introduced, the association did not interfere with its leaf production.

Similarly, we observed that mustard was not influenced by kale intercropping in either adopted spacing. Generally, mustard yield in the monoculture system was 2.80 t/ha, not differing from the yield when intercropped with kale in spacing E_1 (2.37 t/ha) or spacing E_2 (2.54 t/ha).

Possibly, a facilitation mechanism occurred in the kale and mustard intercropping system, which happens when one species provides some benefit to another, positively altering the environment, although not necessarily in a reciprocal manner (Vandermeer, 1990). Thus, it can be inferred that there is weak competition between these two crops in the intercropping system, as they utilize different ecosystem components, or they use the same components but in different ways, resulting in facilitative interaction, such as protocooperation. Therefore, following Vandermeer's Competitive Production Principle (1990), higher productivity between two crops is expected when mutual competition is sufficiently weak, compared to their respective monocultures.

In this study, the Competitive Production Principle can also be understood by analyzing the mustard transplanting, which can be considered late, being performed when kale was already 100 days into its cycle. Even so, there were no growth limitations, demonstrating the ability of these crops to coexist, possibly due to different niche exploitation, both above and below ground, avoiding competition for light, water, and nutrients (Barillot *et al*., 2011), a factor closely related to the success of their association.

In managing intercropped systems, the timing of the second species planting will define the start of coexistence, becoming an important factor for the success of intercropping, as it will establish the duration of coexistence between the species, affecting complementarity, considered when the yield of the intercropped system is greater than those obtained in separate monocultures (Cecílio Filho *et al*., 2010). Thus, the system's efficiency will depend on the species involved and its management, so that they can fully exploit this characteristic between them (Cecílio Filho *et al*., 2015). This complementarity was observed in the kale and carrot intercropping systems, followed by mustard, due to the results and good performance, showing agronomic promise.

Intercropping is considered agronomically efficient in land use when the Land Use Efficiency Index (LUEI) value exceeds 1.00 (Vandermeer, 1990) and the commercial standard of the crops is achieved. we observed that the intercropping combinations in this study showed complementarity, evidencing a positive effect in this system and suggesting that intercropping provided additional production to the farmer, compared to monoculture, given the LUEI values greater than 1.00 (Table 4).

Table 4. Land Use Efficiency Index (LUEI). individual relative productivity indices of crops (I_A and I_B) and Relative Crops Contribution (RCC) to LUEI in the intercropping of kale-carrot and kale-mustard. in two spacings of kale planting. under organic management. Alegre, UFES, 2020.

Crop system	Kale		Mustard		LUEI[3]
	I_A[1]	RCC (%)	I_B[1]	RCC (%)	
Kale E_1 x carrot	0.93	44.71	1.15	55.28	2.08
Kale E_2 x carrot	0.22	20.56	0.85	79.43	1.07
Crop system	**Kale**		**Mustard**		**LUEI**
	I_A	RCC (%)	I_B	RCC (%)	
Kale E_1 x mustard	0.92	52.27	0.84	47.72	1.76
Kale E_2 x mustard	0.66	42.30	0.90	57.69	1.56

Individual relative productivity indices of crops (I_A and I_B). [2]Relative Crops Contribution (RCC).[3] Land Use Efficiency Index (LUEI).

According to the observed LUEI values, it is possible to affirm that an increase of 108% and 7% of planted area (physical space), adopting kale spacing E_1 and E_2, respectively, would be necessary to achieve the total yields obtained in the kale and carrot intercropping (Table 4). While to achieve the total yields obtained in kale and mustard intercropping, an increase of 76% and 56% of planted area (physical space) for kale spacing E_1 and E_2, respectively, would be necessary (Table 4).

Analyzing the LUEI values for spacing E_2 (kale x carrot and kale x mustard), it is possible to affirm that these were lower than those observed in spacing E_1 (Table 4). This result may indicate possible competition between kale and carrot (E_2) in the early cycle phase, as there was a decrease in kale yield in the intercropped system, compared to that obtained in monoculture. However, as the cycle progressed, kale seemingly recovered performance, as in the mustard intercropping (succession), regardless of the adopted spacing, the yields were similar (proximity between LUEIs).

Thus, analyzing the LUEI in successive intercropping systems, it is observed that the kale x carrot intercropping, combined with the kale x mustard succession, in spacing E_1, is more efficient, as the efficiency gains in land use would be 184% (108% kale x carrot + 76% kale x mustard), while with spacing E_2, it would be 63% (7% kale x carrot + 56% kale x mustard), highlighting that both were positive.

Analyzing the Relative Crops Contribution (RCC) in intercropping, it is noted that in the kale and carrot treatment (E_1), there was a better balance between the contributions of each crop in the system (kale: 44.71% and carrot: 55.28%), while in spacing E_2, there is an imbalance, with a lower contribution of the main crop (kale = 20.56%) compared to the companion crop (carrot = 79.43%) (Table 4). This result is not considered ideal since kale is the main crop. In the successive intercropping (kale x mustard), there was a better balance between the crops for both adopted spacings (Table 4), allowing us to infer that there was no drastic decrease in the performance of the main crop with the introduction of the companion crop, making this a more favorable result.

The profitability observed when adopting spacing E_1 in kale shows that higher profits were observed in the intercropping system, both with carrots and in the succession with mustard, compared to monoculture (Table 5), reinforcing the efficiency already estimated by LUEI, which indicated gains.

However, the results expressed when adopting spacing E_2 in kale show differences, as higher profits were observed in the monoculture system of kale compared to the intercropping of both crops (Table 5). This result is possibly associated with the drop of kale productivity, the main crop in this system (E_2).

Table 5. Gross income, Costs, Profits, Benefit/Cost ratio for intercropping and monoculture of kale x carrot and kale x mustard in two kale spacings. Alegre, UFES, 2020.

Crop system	Gross income per crop[1] (U$)	System gross income[1] (U$)	Costs[2] (U$)	Profits (U$)	Benefit/Cost ratio (BCR)
Spacing E_1					
Kale x Carrot					
Kale monoculture	9.899.51[3]	9.899.51	1.311.56	8.587.95	7.54
Carrot monoculture	6.855.46	6.855.46	3.307.37	3.548.09	2.07
Intercropped kale	9.264.84	17.155.46	3.867.41	13.288.05	4.43
Intercropped carrot	7890.62				
Kale x Mustard					
Kale monoculture	4.436.13	4.436.13	835.76*	3.600.37	5.30
Mustard monoculture	1.203.12	1.203.12	379.83	823.29	3.16
Intercropped kale	4.089.35	5.107.70	693.25	4.414.45	7.36
Intercropped mustard	1.018.35				
Intercropped Kale					
Kale x Carrot					
Kale monoculture	31.563.28	31.563.28	2.338.82	29.224.46	13.49
Carrot monoculture	6.855.46	6.855.46	3.307.37	3.548.09	2.07
Intercropped kale	6.752.34	12.631.24	3.648.56	8.982.68	3.46
Intercropped carrot	5.878.90				
Kale x Mustard					
Kale monoculture	5.391.40	5.391.40	1.785.23	3.606.17	3.02
Mustard monoculture	1.203.12	1.203.12	379.83	823.29	3.16
Intercropped kale	2.723.77	3815.17	939.95	2.875.22	4.05
Intercropped mustard	1.091.40				

[1]R$ 3.35/kg of kale. R$ 2.00/kg of carrot. R$ 2.20/kg of mustard. Price paid to the producer at CEASA-ES. on September 5th 2023. [2]Production cost of one hectare of carrot, kale and mustard in monoculture and intercropping of kale with carrot and kale with mustard (Table 1). [3]Value based on the exchange rate of the dollar in the Brazilian market (R$ 5.12/U$ 1.00). in September 2023. *The operational costs of the monocultures of kale, equivalent to the period of intercropping with mustard were estimated based on the maintenance cultural practices, harvesting. and tax charges, considering that the crop was already established.

The return on investment is a crucial analysis concerning these systems and can be estimated through the benefit/cost ratio (BCR). It is observed that the systems were capable of providing a return on investment, each with its particularities. Adopting kale spacing E_1 intercropped with carrots, a value of $4.43 was obtained, meaning that for every $1.00 invested, the producer would get a return of $4.43, while in intercropping with mustard, the return is $7.36 for every dollar invested. Adopting kale spacing E_2, the return was $3.46 and $4.05 in intercropping with carrots and mustard, respectively (Table 5).

Carrots have higher costs due to seeds, irrigation, thinning, harvesting, and classification, which reduces investment returns. This is evident in the intercropping results with this crop, where the BCR was lower than in kale monoculture (E_1 and E_2), which is related to the costs of including the companion crop in the system, the opposite being observed in mustard intercropping. This demonstrates the importance of choosing the right companion crop for the system's success and maximizing investment.

Thus, the influence of crop arrangements (adopted spacings) and the correct choice of companion crops on the agronomic yield (production per unit area) of intercropping systems, as well as the economic yield (profitability and return) of the systems, is clear.

The kale-carrot intercropping, followed by kale-mustard (kale in spacing 1.0 x 0.5 m), showed good yield and land use efficiency of 184%, with higher profitability than monoculture.

The kale-carrot intercropping, followed by kale-mustard (kale in spacing 0.5 x 0.5 m), also showed agronomic efficiency (63%) and positive economic yield but with lower profitability than monoculture.

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