

Agroeconomic viability of intercropping taro and okra plants according to planting dates and plant arrangements

Viabilidad agroeconómica del cultivo intercalado de plantas de taro y okra según fechas de siembra y disposición de las plantas

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ABSTRACT

Intercropping is a cultivation system that aims to achieve high productivity per unit area and promote the sustainability of the production system. The objective of this work is to evaluate the agronomic viability and economic profitability of intercropping taro with okra plants. The research was conducted in an experimental field between October 2011 and June 2012. In total, nine treatments from four intercrops of taro with okra plants were evaluated: okra was planted at two time points, 0 days and 30 days after the taro planting, and two arrangements of okra plants, one plant at 30 cm and two plants at 60 cm. We used a randomized block experimental design with four replications and determined the indexes of SPAD, LAI, K, and the productivity and economic indexes. The intercropping systems were agronomically viable by presenting a Land Use Efficiency (LUE) value above 1. When okra was intercropped at the same time as taro, the best results for Profitability Index (PI), economic yield, and Rate of Return (RR) were achieved. The treatment with one okra plant at 30 cm, intercropped at 0 DAP (Days After Planting) taro presented the best results for RR and PI.

Keywords: *Colocasia esculenta*, *Abelmoschus esculentus*, Profitability, Sustainability, Family farming.

RESUMEN

*El cultivo intercalado es una práctica agrícola que tiene el propósito de lograr una alta productividad por unidad de área y promover la sostenibilidad del sistema de producción. El objetivo de este trabajo fue evaluar la viabilidad agronómica y la rentabilidad económica del cultivo intercalado de taro o malanga (*Colocasia esculenta*) con plantas de okra (*Abelmoschus esculentus*). El ensayo se realizó en un campo experimental entre octubre de 2011 y junio de 2012. En total se evaluaron nueve tratamientos de cuatro cultivos intercalados de malanga con plantas de okra. Se sembró okra en dos períodos, 0 días y 30 días después de la siembra de taro, y a dos ubicaciones de plantas de okra, una planta a 30 cm y dos plantas a 60 cm. Se utilizó un diseño experimental de bloques al azar con cuatro repeticiones y se determinaron los índices de SPAD, IAF, K, y los índices de productividad y económicos. Todos los sistemas de intercalado fueron agronómicamente viables y presentaron un valor de eficiencia en el uso del suelo (ES) por encima de 1. Cuando la okra se intercaló en el mismo momento que el taro, se lograron los mejores resultados para índice de rentabilidad (IR), rendimiento económico y tasa de retorno (TR). El tratamiento con una planta de okra cada 30 cm, sembrado al 0 día posterior al plantío, mostró los mayores valores de TR y IR.*

Palabras clave: *Colocasia esculenta*, *Abelmoschus esculentus*, Rentabilidad, Sustentabilidad, Agricultura familiar.

Introduction

Vegetable production is a typical activity on small family farms, whether for subsistence or the commercialization of the agricultural surplus. Small

farms have diversified their agricultural production but are still limited by land size. However, modern day farmers are also concerned with preserving natural resources (Montezano and Peil, 2006). For such concerns, intercropping systems can be a very

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effective cultural practice. The advantages offered by these systems, in contrast to monocropping, include better use of natural resources, organic benefits for populations, reduction of pests, and higher protection against soil erosion (Salgado *et al.*, 2006).

Although used in various parts of the world, farming systems in a consortium with vegetable crops face challenges regarding the determination of the crops to be intercropped, their respective management practices, and their viability as cropping strategies (Montezano and Peil, 2006).

Thus, identifying species and more suitable arrangements are essential to improve the efficiency of vegetable intercropping systems.

Taro [*Colocasia esculenta* (L.) Schott] is a tropical vegetable of the *Araceae* family that is considered positive in terms of alternative farming, such as resistance to adverse environmental and biological factors. Moreover, having a long growth cycle (about nine months) and partial shade tolerance is a unique candidate for intercropping. However, there are few studies in the literature involving the intercropping of taro with other vegetables – these include taro with sweet corn (Puiatti *et al.*, 2000); taro with carrot and lettuce (Heredia Zárate *et al.*, 2006); taro with chicory (Heredia Zárate *et al.*, 2007) and taro with bean-pod (Vieira *et al.*, 2014).

In intercropping systems, sunlight competition between plants is one of the most important considerations. The Leaf Area Index (LAI) and light extinction coefficient (k) are tools to determine the rate of sunlight interference. Studies involving the use of fast-growing green manure plants such as guandu (Oliveira *et al.*, 2006) and sunn hemp (*Crotalaria juncea*) (Oliveira *et al.*, 2004; 2007) in association with taro and its tolerance to artificial shading (Gondim *et al.*, 2007) demonstrate that it is possible to intercrop taro with plants of a higher growth rate without negative consequences of light competition.

One vegetable with the potential to be used in intercropping with taro is the okra plant [*Abelmoschus esculentus* (L.) Moench]. Okra is a vegetable that belongs to the *Malvaceae* family and is cultivated mainly in tropical regions. This crop is amenable to family farming, especially because it creates jobs in product production, classification, and packing, thus generating economic growth in the smallholder farming sector (Sediyama *et al.*, 2009). Okra has climatic requirements similar to taro, with a continuous harvest season starting around 65 days

after planting and can last for about six months (Sonnenberg and Silva, 2002). The precocity in production compared to taro and relatively long harvest period would allow an earlier financial return to the farmer, making it an attractive option for intercropping with taro.

Intercropped farming systems consist of spatial and temporal combinations of crops in an area. The plant spacing used for the cultivation of okra may vary according to the farmer's planning and interests. However, the spacing is very important and has a large influence on flowering, the number of productive stems, fruit production per plant, and crop productivity (Sonnenberg and Silva, 2002).

In an intercropping system of vegetables, some of the species involved may suffer from stress due to competing for light, water, nutrients and space (Montezano and Peil, 2006). The evaluation of the SPAD index is an important tool to determine the nutritional status (concerning nitrogen) (Pôrto *et al.* 2011, 2014).

This study, in particular, aimed to evaluate the agronomic viability and the economic profitability of taro and okra in two seasons of intercropping and with two different plant arrangements.

Material and methods

The study was conducted in the field at Universidade Federal de Viçosa (UFV), Viçosa, Minas Gerais, Brazil, from 9/30/2011 to 6/11/2012. Soil samples from the experimental area, a red-yellow cambisolic Argisole, taken at a depth of 0-20 cm, revealed the following results: $\text{pH}_{(\text{water})} = 6,4$; $\text{P} = 180$ e $\text{K} = 102$ mg dm^{-3} ; $\text{Ca}^{2+} = 5,0$; $\text{Mg}^{2+} = 0,7$ e $\text{Al}^{3+} = 0,0$ cmol_c dm^{-3} ; $\text{B} = 0,7$; $\text{Fe} = 188$; $\text{Mn} = 104,4$; $\text{Zn} = 12$ e $\text{Cu} = 3,5$ mg dm^{-3} ; $\text{MO} = 2,7$ dag kg^{-1} ; $(\text{H}+\text{Al}) = 2,48$; $\text{SB} = 5,10$; $\text{CEC}_{(0)} = 9,05$ and $\text{CEC}_{(T)} = 8,11$ cmol_c dm^{-3} ; $\text{V} = 73\%$ and $\text{P-rem} = 29,9$ mg L^{-1} .

The nine treatments consisted of differing taro and okra intercropping combinations with two planting periods and two planting arrangements (Table 1). A randomized complete block design with four replications was used. The plot consisted of four rows, each 3.0 m long and spaced 1.0 m apart. Each row contained ten taro plants spaced at 0.30 m. The net area consisted of a 4.0 m^2 area with its borders set at 0.5 m from each row of taro and each plot's border.

Taro planting was done at a depth of 0.12 m using rhizomes of the "Japanese" taro (BGH 5925)

cultivar with an average mass of 60 g, obtained from the Germplasm Bank of Vegetables from UFV. Seeds of okra “Santa Cruz 47” cultivar plants were planted at a depth of 0.05 m; in the intercropping treatments, they were planted between the taro plants. 15 days after the emergence of okra plants, thinning was performed to leave one plant every 0.30 m or two plants each 0.60 m, according to the treatment (Table 1). The fertilization regime was based on chemical and physical soil analyzes and on recommendations for the crops, according to (Ribeiro, 1999). Therefore, the intercropped system received fertilization recommended for both plants, according to Cecílio Filho *et al.* (2008). When necessary, hoe scarifying and sprinkler irrigation were used.

At 110, 125, 140, 155, and 170 days after taro planting (DAP) –in both the monoculture and intercropped treatments– estimates of leaf area index (LAI) and light extinction coefficient (k) were calculated with a ceptometer (AccuPAR model LP-80), as well as measurements of SPAD index with a portable chlorophyll meter SPAD-502 (Minolta Camera Co. Ltd.). LAI and k were determined by placing a bar along the planting rows at various points within the plot. The determination of the SPAD index was performed in the second fully expanded leaf of the apex of four plants from the useful rows. Three measurements were made per leaf (one in each lobe and one at the apex), totaling 12 measurements per plot, with the mean being used to represent the treatments.

In eight okra plants from the two central rows of each experimental unit, the time in which 50% of the

plants reached the flowering, and the beginning of harvest was evaluated. The vegetables were harvested when they reached the characteristic commercial size of the variety. The crops were divided, harvested twice per week, and lasted about four months (Tables 1 and 3). The vegetables were selected, counted, measured, and weighed. The malformed ones, with an incidence of interocular cavities or holes caused by insects, were considered unmarketable. The following aspects were determined: yield of the mass of marketable vegetables fresh matter, the diameter and vegetable length, and number of the marketable vegetables per plant. At the end of the harvest, plants were cut at ground level, and height, the number of leaves, side branches per plant, length of internodes, and dry matter were also determined.

At 254 days after planting, eight plants per plot were harvested and evaluated for the production of fresh matter and the number of rhizomes. The mother rhizomes were separated, and daughter rhizomes were classified based on transverse diameter, according to Puiatti *et al.* (2000), in the following classes: Big Daughter (BD), Medium (MD), small (SD), and reject (REJ). The total productivity consisted of the summation of the yields of mother rhizomes and all classes of daughter rhizomes. The summations of classes (BD + MD + SD) were considered marketable.

The efficiency of the intercropped systems was measured by the following agro-economic indicators: index of efficient use of land (EUL); gross income (GR); net income (NI); monetary

Table 1. Treatments with dates of plantation and harvesting of taro and okra cultures, in monocrop and intercropped, and seasons of the implantation of okra plants and arrangements used.

Treatments	Taro		Okra			
	Set up	Harvest	Set up	Harvest	EQ1	Arrangements
1-. (Taro monocrop)	9/30/2011	6/11/2012		None		
2-. (Taro intercropped)	9/30/2011	6/11/2012	9/30/2011	4/24/2012	0	1 plant/30 cm of okra
3-. (Taro intercropped)	9/30/2011	6/11/2012	9/30/2011	4/24/2012	0	2 plants/60 cm of okra
4-. (Okra intercropped)		None	9/30/2011	4/24/2012	0	1 plant/30 cm of okra
5-. (Okra intercropped)		None	9/30/2011	4/24/2012	0	2 plants/60cm of okra
6-. (Taro intercropped)	9/30/2011	6/11/2012	10/30/2011	5/15/2012	30	1 plant/30 cm of okra
7-. (Taro intercropped)	9/30/2011	6/11/2012	10/30/2011	5/15/2012	30	2 plants/60 cm of okra
8-. (Okra monocrop)		None	10/30/2011	5/15/2012	30	1 plant/30 cm of okra
9-. (Okra monocrop)		None	10/30/2011	5/15/2012	30	2 plants/60 cm of okra

1/EQ = Season of implantation of okra plants (days after taro plantation) intercropped with taro and the respective monocultures. The date corresponds to the last sample taken.

Table 2. Yields, in mass of fresh matter, of mother rhizomes (MR), total (TR), commercial (CR), big daughter (BD), medium daughter (MD), small daughter (SD), daughter reject (REJ) and number of commercial daughter rhizomes per plant (NCDP) of taro plants in monoculture and in intercropping with okra plants.

Treatments	MR	TR	CR	BD	MD	SD	REJ	NCDP
	t ha ⁻¹							rhizome
1-. Taro (monocrop)	17.04a	54.38a	30.90a	9.52a	15.07a	6.31a	6.43a	11.06a
2-. Intercropping- 0 DAP/1 pl/hole	17.24a	57.90a	34.51a	10.71a	17.18a	6.61a	6.14a	12.00a
3-. Intercropping- 0 DAP/2 pl/hole	18.69a	59.50a	33.72a	9.16a	16.20a	8.37a	7.10a	12.13a
6-. Intercropping- 30 DAP/1 pl/hole	20.62a	65.08a	36.86a	11.33a	18.85a	6.67a	7.60a	12.38a
7-. Intercropping- 30 DAP/2 pl/hole	21.63a	61.69a	33.69a	10.86a	15.87a	6.95a	6.32a	11.31a
CV (%)	22.23	12.83	15.63	46.29	18.16	36.54	23.78	14.87
Mean	19.05	59.70	33.94	10.32	16.63	6.98	6.72	11.77

Means in the columns followed by at least one same letter do not differ by the Tukey test at 95% confidence; means in columns followed by an asterisk (*) differ from control at 95% confidence.

Table 3. Mean values observed in the orthogonal contrasts (C) among treatments (T) of intercropped cultures and okra monocrop (\hat{Y}_1 , \hat{Y}_2 , \hat{Y}_3 and \hat{Y}_4), among intercropped okra (\hat{Y}_5 and \hat{Y}_6), and among monocrop of okra (\hat{Y}_7 and \hat{Y}_8) in two periods of association and arrangements of plants used for the characteristics of 50% of flowering plants (50% F), beginning of fruit production (BVP), number of marketable fruits per plant (NMVP), number of leaves per plant (NLP), number of lateral branches per plant (NLBP), length of internodes (LI), vegetable diameter (VD), length of fruits (LF), plant height (PH), mass of dry matter of the shoots (DMP) and commercial productivity of fruit (CPF) of the after the after harvest of them all.

C	T	50%F	BVP	NMVP	NLP	NLBP	LI	VD	LF	PH	DMP	CPF
		DAP	fruit/plant	leaf/plant	branche/plant	cm			t ha ⁻¹			
\hat{Y}_1	2	85.5	89.5	49.56	60.87	0.72	4.97	1.46	14.47	283.93	4.64	32.88
	4	81.0	88.0	60.44	61.90	2.47	4.51	1.49	14.45	265.43	5.05	41.12
\hat{Y}_2	3	88.0	91.0	42.16	53.56	0.47	5.07	1.39	14.27	253.74	3.50	28.19
	5	81.5	88.0	55.56	59.18	1.71	4.53	1.45	14.00	249.59	4.85	35.44
\hat{Y}_3	6	109.5	96.5	17.38	32.59	0.18	5.84	1.44	13.82	183.65	1.73	10.74
	8	78.25	81.5	61.81	59.18	2.22	4.51	1.46	14.25	247.25	4.48	39.02
\hat{Y}_4	7	109.5	100.5	15.53	29.59	0.15	6.11	1.43	13.35	173.12	1.44	8.78
	9	76.25	80.75	53.10	53.93	1.90	4.76	1.47	14.27	238.56	3.87	33.99
\hat{Y}_5	2	85.5	89.5	49.56	60.87	0.72	4.97	1.46	14.47	283.93	4.64	32.88
	6	109.5	96.5	17.38	32.59	0.18	5.84	1.44	13.82	183.65	1.73	10.74
\hat{Y}_6	3	88.0	91.0	42.16	53.56	0.47	5.07	1.39	14.27	253.74	3.50	28.19
	7	109.5	100.5	15.53	29.59	0.15	6.11	1.43	13.35	173.12	1.44	8.78
\hat{Y}_7	4	81.0	88.0	60.44	61.90	2.47	4.51	1.49	14.45	265.43	5.04	41.12
	8	78.25	81.5	61.81	59.18	2.22	4.51	1.46	14.25	247.25	4.48	39.02
\hat{Y}_8	5	81.5	88.0	55.56	59.18	1.71	4.53	1.45	14.00	249.59	4.85	35.44
	9	76.25	80.75	53.10	53.93	1.90	4.76	1.47	14.27	238.56	3.87	33.99

ns; **, *: respectively, not significant and significant at 99 and 95% confidence by the F test;

\hat{Y}_1 - Okra intercropped with taro at 0 DAP-1 plant/30 cm vs. Okra monoculture at 0 DAP - 1 plant/30 cm;

\hat{Y}_2 - Okra intercropped with taro at 0 DAP-2 plants/60 cm vs. Okra monoculture at 0 DAP - 2 plants/60 cm;

\hat{Y}_3 - Okra intercropped with taro at 30 DAP-1 plant/30 cm vs. Okra monoculture at 30 DAP - 1 plant/30 cm;

\hat{Y}_4 - Okra intercropped with taro at 30 DAP-2 plants/60 cm vs. Okra monoculture at 30 DAP- 2 plants/60 cm;

\hat{Y}_5 - Okra intercropped with taro at - 0 DAP-1 pl/30 cm vs. Okra intercropped with taro at 30 DAP-1 pl/30 cm;

\hat{Y}_6 - Okra intercropped with taro at - 0 DAP-2 pl/60 cm vs. Okra intercropped with taro at 30 DAP-2pl/60 cm;

\hat{Y}_7 - Okra monocrop - 0 DAP- 1 pl/30 cm vs. Okra monoculture at- 30 DAP- 1 pl/30 cm;

\hat{Y}_8 - Okra monocrop - 0 DAP- 2 pl/60 cm vs. Okra monoculture at- 30 DAP- 2 pl/60 cm.

advantage (MA); corrected monetary advantage (CMA); rate of return (RR) and profitability index (PI). The EUL index was calculated as follows: $EUL = (I_{\text{taro}}/S_{\text{taro}}) + (I_{\text{okra}}/S_{\text{okra}})$, in which I and S represent the productivity of the intercropped and monoculture systems, respectively.

The gross revenue (GR) was obtained by multiplying the productivity of the crops in each treatment by the value of the product paid to producers in the Ceasa (supply center) of Contagem, a city of Minas Gerais, Brazil (CEASA-MG, 2012). For okra, the corresponding prices of each day of the harvest were considered, while, for taro, product prices in the days of the experiment's harvesting were used.

Net income (NI) was calculated by subtracting from the gross income the total operating cost (TOC). The TOC was calculated for each treatment, considering the coefficients of inputs and services used in a hectare of taro (Helmich *et al.*, 2010) and okra (EMATER, 2012). The cost of inputs, services, packaging, and transport were specific to the region of Viçosa in the period between 2011 June and September 2012. The monetary and the corrected monetary advantages were calculated using the following expressions: $MA = GR \times (EUL - 1)/EUL$ and $CMA = NI \times (EUL - 1)/EUL$. The rate of return (RR) per dollar invested in each treatment was obtained by the ratio between gross revenue (GR) and production cost (PC) of each treatment. The profitability index (PI) was obtained from the ratio between the NI and GR, expressed as a percentage per Oliveira *et al.* (2005) and Cecilio Filho *et al.* (2008).

The data obtained were subjected to an analysis of variance. The treatment means were compared using Tukey's test and compared to the control by Dunnett's test; orthogonal contrasts of interest were compared with an F test, all at 95% confidence. The characteristics SPAD, LAI, and k, evaluated over five seasons, were subjected to simple regression analysis; the models were chosen based on the significance of the regression coefficient, the determination coefficient, and biological behavior. The software SAEG 9.1 (SAEG, 2007) was used to perform the statistics.

Results and discussion

Taro production

No differences were found between the treatments, the intercropped system, and the control

(taro monoculture) regarding mass production of rhizomes and number per plant (Table 2). The productivity of commercial rhizomes ranged from 30.9 t ha⁻¹ (control) to 36.86 t ha⁻¹ (intercropping 30 DAP 30/1 plant/hole). Although the intercropping started at 30 DAP taro in the latter treatment, the productivity lasted until the eighth month. Under the climate conditions of Viçosa, Minas Gerais, Brazil, for the 'Japanese' taro, Gondim *et al.* (2007) obtained a yield of 41.69 t ha⁻¹ with the taro grown under direct sunlight, and the productivity varied from 22.3 to 35.0 t ha⁻¹ when it was grown under shading rates of 50, 30 and 18% during certain stages of the cultivation process. The intensity of 18% shade, either throughout the whole cycle or in the initial and intermediate periods, was the treatment that least affected plant growth and biomass production of marketable daughter rhizomes.

Taro intercropped with another vegetable presented different results, with higher commercial production of "Chinese" taro in monocultures compared to the intercropped system with chicory (Heredia Zarate *et al.*, 2007) and also with lettuce "Quatro Estações" - Four Seasons (Heredia Zarate *et al.*, 2006). The intercropping of taro with sweet corn "Cristal", planted 40 days after taro, also affected the production of rhizomes concerning the monoculture of taro (Puiatti *et al.*, 2000). In an intercalated system with *Crotalaria juncea*, taro presented lower productivity of daughter rhizomes when the plants were not trimmed during the development of the intercropping (Oliveira *et al.*, 2007). In another study, Oliveira *et al.* (2004) found no decrease in productivity of taro even when it was in permanent association with *Crotalaria juncea*.

The arrangements are important management factors to be manipulated to improve the use of resources and for the efficiency of vegetable intercropping. Most species of the *Araceae* family are considered shade-tolerant plants. Gondim *et al.* (2007) and Oliveira *et al.* (2011) suggest that in the case of the association of taro with other crops of higher growth habit, the associated crop may provide shading with an intensity of up to 25% without causing a significant decrease in the production of commercial rhizomes.

Although not statistically different from the control, intercropping treatments provided higher numeric values in almost all productive characteristics of taro, especially when the intercropping was established 30 DAP (Table 2). In these cases, taro

may have benefited from the fertilization of okra and the partial shading provided by okra.

Okra production

Okra monocultures planted at 30 DAP, with either one or two plants/holes, showed accelerated maturation concerning the intercropping treatments (\hat{Y}_3 and \hat{Y}_4 Orthogonal contrasts). Additionally, the maturation rate of the intercropping system with two plants/holes at 30 DAP was slower than in the intercropping at 0 DAP (\hat{Y}_6 Orthogonal contrast). The intercropped system planted at 0 DAP and 30 DAP, with one plant/hole every 0.30 m (\hat{Y}_1 and \hat{Y}_3) or two plants/hole every 0.60 m (\hat{Y}_2 and \hat{Y}_4) resulted in the reduction of commercial vegetables and lateral branches and lower productivity of marketable vegetables/plants compared with the monoculture of okra plants (Table 3). Intercropping starting at 30 DAP (\hat{Y}_3 and \hat{Y}_4) still had significantly lower values of NLP, AP, LF, and DMP.

Comparing the intercropped okra planted at 0 DAP with the 30 DAP using one plant/hole (\hat{Y}_5), we verify that the 30 DAP treatment had less time to flowering, lower values of LI, and higher NVMP, NLP, PH, DMP, and CPF. The same behavior was observed in the arrangement of two plants per hole (\hat{Y}_6), with lower values of BVP and higher LF values. Comparing the okra monocultures in two periods of cultivation and two experimental arrangements (\hat{Y}_7 and \hat{Y}_8), we found no difference for the characteristics evaluated (Table 3) except that BVP values were lower and the DMP was higher in the monocrop (\hat{Y}_8). These results show clearly that intercropped okra competed with taro plants, especially when the okra planting was performed at 30 DAP regarding taro.

The low temperatures observed in the initial phase of the experiment delayed the development of okra plants and benefited taro plants in the competition for growth. Okra is one of the most demanding vegetables concerning heat and has higher fruit production in temperatures ranging from 21.1 to 29.4 °C (Sonnenberg and Silva, 2002).

The effect of taro plants on okra plants planted at 30 DAP may be related to the competition for water, light, and nutrients. Between 75 and 165 DAP, a high growth rate and absorption of nutrients occur in taro plants (Puiatti *et al.*, 1992); in this same period, okra was still in the establishment period, in this period okra has around 30% of its

mature root mass (Paes *et al.*, 2012). Thus, taro performed better in this system and delayed the development of okra plants.

Studies about the okra intercropped with other vegetables are not common in the literature. When associated with radish and lettuce using the treatments: lettuce and open space okra (AL/Q1), lettuce and traditional space okra (AL/Q2), radish and open space okra (Rb/Q1), radish and traditional space okra (Rb/Q2), and triple intercropping lettuce, radish, and open space okra (AL/Rb/Q1) and lettuce, radish, and traditional space okra (AL/Rb/Q2), Sugasti *et al.* (2013) verified that the treatment that showed the highest yield per plant was AL/Q1/Rb, with 0.51 kg. m⁻².

A reduction in the productivity and height of okra “Santa Cruz 47” cultivar plants was verified in an intercropping system with cowpea (*Vigna unguiculata* (L.) Walp] when the crops were planted on the same day (Zuchi *et al.*, 2012). The mean productivity of 33.31 t ha⁻¹ and the plant height of 125 cm obtained by the authors in their monoculture system were lower than those observed in this study, ranging from 33.99 to 41.12 t ha⁻¹, and from 238.56 to 265.43 cm, respectively. This observation highlights the importance of plant height for the productivity of fruit.

Agroeconomic indicators

Intercropping presented EUL values ranging from 1.35 to 1.92, demonstrating a better use of available environmental resources in comparison to monocultures (Table 4). These values mean that it takes 35 - 92% more area for single monocultures to achieve the equivalent production of the intercropped cultures in one hectare.

The EUL values in the okra intercropping treatments planted at the same time as taro (0 DAP) were higher than those observed in the treatments where okra was planted 30 DAP. This behavior was observed for all agro-economic indicators used and was due to the higher production of okra achieved through the implementation of concomitant cultivation.

Higher EUL values and gross income also were found in intercropped cultivations of taro and beanpod (Vieira *et al.*, 2014). In an intercropping of taro with carrot and taro with lettuce, Heredia Zarate *et al.* (2006) obtained EUL values of 6% and 83%, respectively. The increase in productivity per area unit is an important reason to consider cultivating two or more crops. This system allows better use of

Table 4. Agroeconomic indicators, index of efficient use of land (EUL), gross revenue (GR); net income (NI); monetary advantage (MA), corrected monetary advantage (CMA); the rate of return (RR) and profitability index (PI) observed in okra-taro intercropping and monocultures.

Treatment	EUL	GR	US\$ ha ⁻¹			RR	PI
			NI	MA	CMA		
						US\$/US\$	%
1- Taro (monocrop)	1.00c	8,636.76e	4,081.63e	–	–	1.89 bc	47.5 ab
2- Intercropping/0DAP 1pl/hole	1.92a*	24,625.66a*	13,311.00a*	11,769.62a	6,384.62a	0.72ab*	53.65a*
3- Intercropping/0DAP 2pl/hole	1.89a*	22,273.63ab*	11,593.5ab*	10,419.17a	5,421.73a	0.69ab	52.02a
6- Intercropping/30DAP 1pl/hole	1.48b*	14,685.47cd*	5,867.70de	4,602.32b	1,915.60b	0.55cd	39.27bc
7- Intercropping/30DAP 2pl/hole	1.35bc*	13,059.93de*	4,655.87de	3,343.74bc	1,259.66b	0.51d	34.75c
4- Okra monocrop/0DAP 1pl/hole	1.00c	18,956.87bc*	10,419.64abc*	–	–	0.73a*	54.41a*
5- Okra monocrop/0DAP 2pl/hole	1.00c	16,260.83cd*	8,404.91bcd*	–	–	0.68ab	51.05a
8- Okra monocrop/30DAP 1pl/hole	1.00c	16,939.85cd*	8,649.52bcd*	–	–	0.68ab	50.55a
9- Okra monocrop/30DAP 2pl/hole	1.00c	15,079.33cd*	7,390.33cde*	–	–	0.65ab	48.65a

Means in the columns followed by at least one same letter do not differ by the Tukey test at 95% confidence; means in the columns followed by an asterisk (*) differ from control at 95% confidence. Dollar exchange rate: US\$ 1.00 = R\$ 3.00.

the land and other available resources, resulting in higher economic return, most of the time.

Nevertheless, the EUL value alone is not sufficient to decide if intercropping is profitable, as income indicators are needed to confirm profitability. Despite presenting EUL values higher than those observed for the taro monoculture, the net income values in the intercropping system where okra was planted 30 days after taro had no significant difference concerning the taro monoculture. The low productivity observed in the okra plants during this period, due to growing competition, contributed to the net income being higher than the control. The main crop should be defined as the implementation of a crop consortium. In this study, the main crop was taro, and it was not affected by intercropping; however, if we had chosen okra as the main culture, and intercropping system with okra planting occurring at 30 DAP taro would not have been recommended since okra productivity was lower than in the monoculture systems.

Regarding the RR and the PI, higher values were obtained in intercropping treatments planted at 0 DAP. Amongst these, the arrangements with one plant every 0.30 m were the best performing for RR and PI. Therefore, a higher economic return is estimated when okra is planted at the same time as taro, with a plant spacing of 0.30 m and one plant per hole.

SPAD, IAF, and k

A significant interaction between [treatment x period of evaluation] for SPAD values was observed.

In each period, from 125 DAP, in treatments with the okra was planted 30 DAP, the SPAD values were higher than those calculated in the taro monoculture; at 155 DAP, those values were also higher for the treatments in which taro and okra were planted at the same time (Table 5). Treatments that presented higher SPAD values also presented higher production levels of commercial taro rhizomes (Table 2) and lower production of commercial okra fruit (Table 3). These treatments demonstrated better development of the taro crop (something that affected okra plants). Although the intercropping treatments received the fertilizations recommended for both cultures, the poor development of the okra plant (in the planting carried out 30 DAP) caused more nutrients (mainly N) to be available to taro, which resulted in the higher SPAD values. Positive correlations between SPAD indexes and content of N in leaves have been verified in vegetables such as summer squash (Pôrto *et al.*, 2011) and Japanese cucumber (Pôrto *et al.* 2014).

In the regression analysis for the SPAD index, from the period of 110 to 170 DAP taro, an adjustment was possible only for intercropping treatments with two plants/holes implemented at 0 and 30 DAP (Table 6). In these intercropping systems, the SPAD index presented a decrease and a linear increase, respectively, corroborating the previous results of the greater and minor competition of okra plants with taro intercropping occurring 0 DAP and 30 DAP, respectively.

No significant interaction between [treatment x time] for LAI was observed. In the mean evaluations, the treatment in which the okra plant was planted 30

Table 5. Values of SPAD index measured in leaves of taro plants 110, 125, 140, 145 and 170 days after the taro plantation (DAP) and mean values of five evaluations of Leaf Area Index (LAI) carried out during the growth of the taro monocrop and in the intercropping with the okra plant established 0 and 30 days after the taro plantation (DAP) with 1 or 2 plants of okra per hole.

Treatment	SPAD Index					LAI
	110	125	140	155	170	
Taro (monocrop)	52.42a	48.40b	53.48b	47.63b	50.12c	4.33b
Intercropping-0DAP 1 pl/hole	57.68a	54.90ab	57.00ab	50.90b	51.18bc	4.20b
Intercropping-0DAP 2 pls/hole	58.06a	54.70ab	56.47ab	50.06b	48.13c	4.26b
Intercropping-30DAP 1 pl/hole	57.95a	56.40a*	61.92a*	58.55a*	58.53ab*	5.30a*
Intercropping-30DAP 2 pls/hole	58.31a	56.53a*	62.72a*	60.69a*	65.67a*	4.72ab
CV(%) main plot	10.33	10.33	10.33	10.33	10.33	18.70
CV(%) sub-plot	5.31	5.31	5.31	5.31	5.31	17.85

Means in the columns followed by at least one same letter do not differ by the Tukey test at 95% confidence; means in the columns followed by an asterisk (*) differ from control at 95% confidence.

Table 6. SPAD index values of taro in monoculture treatments and in the intercropping with okra; and for the leaf area index (LAI) and light extinction coefficient (k) according to the number of days after planting (DAP), with the respective determination coefficient (r^2).

Treatment/Variable	Equation	r^2
1-Taro monocrop	$SPAD = 50.41$	–
2-Intercropping- 0 DAP 1 pl/hole	$SPAD = 54.33$	–
3-Intercropping- 0 DAP 2 pls/hole	$SPAD = 76.3382 - 0.1632 **DAP$	0.84
6-Intercropping- 30 DAP 1 pl/hole	$SPAD = 58.63$	–
7-Intercropping- 30 DAP 2 pls/hole	$SPAD = 43.1598 + 0.1259 **DAP$	0.69
LAI	$SPAD = 13.396500 - 0.063090 **DAP$	0.81
k	$SPAD = 0.143683 + 0.002546 **DAP$	0.86

**Significant at 99% confidence by "t" test.

DAP (with one plant/hole) presented a higher LAI value than the taro monoculture or the intercropping planted at the same time as taro (Table 5). In this treatment, the highest values for rhizome production (Table 2) were observed, demonstrating that LAI is an important physiologic attribute to estimate yield in *Colocasia*. From the period 110 - 170 DAP taro, LAI presented a linear decrease (Table 6), which can be explained by the natural senescence of the aerial parts of taro plants.

There was no significant interaction between [treatment x period], not an even difference among treatments concerning the light extinction coefficient (k). The values of k during the period 110 to 170 DAP of taro presented a linear increase (Table 6). Bernardes *et al.* (2011) obtained values of k varying between 0.44 to 0.99 for a taro monoculture. In this study, we obtain lower values, 0.38 to 0.65. The k is related to the leaf display area and to the angle of leaf inclination; with LAI, these features indicate

the efficiency of the plants in intercepting solar radiation. Studies with this same approach give important answers about the use of solar radiation by plants; however, there are only a few studies regarding this aspect of taro crops.

Conclusions

The intercropping of taro with okra implemented in two periods (0 and 30 days after the planting of taro) and the arrangements (1 or 2 okra plants/hole, with plants at a distance of 30 or 60 cm, respectively) are agronomically feasible considering the efficient use of land (EUL).

In treatments where the crops were implanted concomitantly, the economic indicators - gross income, net income, monetary advantage, and corrected monetary advantage are higher than in treatments where the okra was implemented 30 days after the taro planting.

Higher values of rate of return and profitability index are obtained when planting okra at the same time as taro, with a 30 cm distance between plants, indicating a beneficial arrangement for this intercropping.

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