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Productive and monetary efficiency of radish and coriander intercropping under organic management[1]

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ABSTRACT - The search for cropping systems that aim to have the best area use, optimize production, and guarantee financial profitability to the producer and their establishment in the field are challenges of modern research. Thus, the objective of this study was to evaluate the productive and monetary viability of intercropping radish and coriander fertilized with equitable amounts of hairy woodrose and roostertree biomass from the Caatinga ecosystem at different coriander population densities in two cropping seasons. The experimental design used was randomized blocks, with treatments arranged in a 4 × 4 factorial scheme with four replications. The first factor was constituted by four equitable amounts of hairy woodrose and roostertree biomass (20, 35, 50 and 65 t ha^{-1} on a dry basis), and the second factor was constituted by coriander population densities (40, 60, 80 and 100% of the recommended density for monocropping, RDM). The greatest agronomic and monetary advantages of intercropping radish with coriander were obtained with a land equivalent coefficient and a monetary equivalence ratio of 0.42 and 0.76, respectively, in the amounts of hairy woodrose and roostertree biomass of 20 and 39 t ha^{-1} added to the soil, in the coriander population density of 100% of the RDM. The coriander green mass yield and commercial productivity of radish roots optimized in the intercropping were 1.25 and 14.90 t ha^{-1} when fertilized with 65 t ha^{-1} of green manures biomass in the coriander population density of 100% RDM.

Key words: *Coriandrum sativum*. *Raphanus sativus*. *Merremia aegyptia*. *Calotropis procera*. Productive and monetary optimization.

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INTRODUCTION

Vegetable cultivation has been characterized as an intensive activity due to the constant use of soil, high investment per area and attractive financial return (Sá *et al.*, 2021). Thus, the search for cropping systems that aim to have the best area use, optimize production, and guarantee financial profitability to the producer and their fixation in the field are challenges of modern research (Sá *et al.*, 2022). Among the technologies that contribute to this end, the intercropping technique consists of the simultaneous cultivation of two or more species with different cycles and vegetative architectures in the same area in the same period of time and sown at different times (Burgess, Cano and Parkes, 2022).

The intercropping system of radish (*Raphanus sativus* L.) and coriander (*Coriandrum sativum* L.) has grown in a semi-arid environment, as they are crops with short cycles and are considered companions for the best use of environmental resources (Oliveira *et al.*, 2019; Rabelo *et al.*, 2019). To obtain good results in this cropping system, the fertilization and planting density of the component crops must be well managed, as they interfere with plant growth (Liu *et al.*, 2023).

The types of organic fertilizer used in Northeast Brazil to produce tuberous and leafy vegetables are the green manures hairy woodrose (*Merremia aegyptia* L.) and roostertree (*Calotropis procera* (Ait.) R. Br.), which are spontaneous plants from the Caatinga ecosystem (Lino *et al.*, 2021; Sá *et al.*, 2021) that have a low cost, are easy to acquire and provide high nutrient levels for crops.

Evaluating the viability of intercropping radish and arugula fertilized with hairy woodrose and roostertree under different leafy crop population densities, Sá *et al.* (2022) obtained greater agroeconomic efficiency from this intercropping. The land equivalent coefficient (LEC) and equivalent monetary ratio (MER) were 0.55 and 1.35, respectively, with 54.75 t ha^{-1} hairy woodrose and 54.55 t ha^{-1} roostertree biomass added to the soil. The planting density of leafy crops is an important factor in determining the fertilizer dose to be used in the system.

Thus, the population density of component crops can promote a series of changes in plant growth and development, dictated by intra- and interspecific competition for environmental resources, thus affecting crop production and its components (Ribeiro *et al.*, 2018). Intercropping coriander (Co), carrot (C) and arugula (R) at three population densities (20Co-50C-20R; 30Co-50C-30R; 40Co-50C-40R; and 50Co-50C-50R (%) of the recommended population for monocropping, RPM), Oliveira *et al.* (2017) obtained the best agroeconomic and productive performance at an intercropping population density of 50Co-50C-50R (%).

The objective of this work was to evaluate the productive and agroeconomic performance of radish–coriander intercropping under different equitable amounts of hairy woodrose and roostertree at different coriander population densities in a semi-arid environment.

MATERIAL AND METHODS

Experiments were conducted from October to December 2021 and from September to November 2022 at the Experimental Farm of Rafael Fernandes, belonging to the Universidade Federal Rural do Semi-Árido (UFERSA), located in the Lagoinha District, 20 km from the municipality of Mossoró, RN, with geographic coordinates 5° 03’ 37” south latitude, 37° 23’ 50” west longitude and approximate altitude of 80 m.

According to the Köppen classification, the climate in the region is ‘BShw’, that is, dry and very hot, with two distinct seasons: a dry one, which generally occurs from June to January, and a rainy one, from February to May (Beck *et al.*, 2018). During the crop development and growth period, no rainfall was observed. The other average meteorological data recorded are presented in Table 1 (Laboratório de Instrumentação, Meteorologia e Climatologia, 2022).

The soils in the experimental areas are classified as Dystrophic Red-Yellow Argisol with a sandy-loam texture (Santos *et al.*, 2018). To evaluate soil fertility, simple

Table 1 - Average meteorological data during the growth and development periods of radish and coriander in the 2021 and 2022 cropping seasons

Cropping seasons	Temperature (°C)			Relative humidity (%)	Solar radiation (MJ m^{-2})	Wind speed (m s^{-1})
	Minimum	Average	Maximum			
2021	23.32	29.90	36.48	67.60	274.80	2.80
2022	22.53	29.38	36.23	62.87	256.41	1.71

Source: Laboratório de Instrumentação, Meteorologia e Climatologia (2022) samples were collected in the 0–20 cm layer and mixed into a composite sample for the analysis of chemical characteristics. These samples were analyzed at the Laboratory of Water, Soil and Plant Tissue Analysis of the Federal Institute of Education, Science and Technology of Ceará - Campus Limoeiro do Norte to determine the chemical attributes, whose results are shown in Table 2.

The experiment was set up in a randomized complete block design with a 4 × 4 factorial scheme and four replications. The first factor consisted of equitable amounts of hairy woodrose and roostertree biomass at doses of 20, 35, 50 and 65 t ha^{-1} on a dry basis, and the second factor consisted of coriander culture population densities of 40, 60, 80 and 100% of the recommended density for monocropping (RDM). The planting densities recommended for monocropping coriander and radish was 1,000.000 and 500.000 pls ha^{-1}, respectively. In each block, plots of radish and coriander in monocropping were added and fertilized with equitable biomass amounts of the green manures optimized by research in the region of 39.43 and 49.56 t ha^{-1} to obtain the agronomic and economic indices of the intercropping systems. The spacing between the radish and coriander plants used in intercropping and monocropping is shown in Table 3.

Radish–coriander intercropping was carried out in alternating strips of 4 rows, with 50% of the area cultivated with radish and 50% cultivated with coriander. In the experimental plots, the four rows of radish were alternated with four rows of coriander flanked by two rows of each crop on each side used as a border. The total area of each plot was 2.88 m^2 (2.40 × 1.20 m), with a useful area of 1.60 m^2 (1.60 × 1.00 m). This harvest area was composed of two central strips of plants, with the first and last plants of each row excluded from the strips.

The monocropping of vegetables was carried out in 6 rows in each plot for a total area of 1.44 m^2 (1.20 × 1.20 m). The harvested area of the plot was 0.80 m^2 (0.80 × 1.00 m), consisting of the 4 central rows of plants and excluding the first and last plants in each row. Radish was planted at a spacing of 0.20 × 0.10 m, and coriander was planted at a spacing of 0.20 × 0.05 m.

Soil preparation consisted of mechanically cleaning the experimental areas with the aid of a tractor with a coupled plow and raising the beds with a rotary bed digger. Subsequently, pre-planting solarization was carried out with transparent plastic of the Vulca Brilho Bril Flex type (30 microns) for 30 days to combat phytopathogenic microorganisms present in the soil that could affect crop productivity (Yadav and Singh, 2017).

Table 2 - Chemical analyzes of the soils in the areas where the experiments were implemented before incorporation in the cropping seasons of 2021 and 2022

Soils	C	OM	pH	EC	P	K	Ca	Mg	Na	Cu	Fe	Mn	Zn	B
	----- g kg^{-1} ----		(H_2O)	dS m^{-1}	--- mg dm^{-3} ---		---------------------------- $mmol_c$ dm^{-3} ------------------------------							
1	7.92	12.97	6.60	0.56	32.00	2.59	23.70	6.50	2.30	0.30	4.80	6.10	2.70	0.50
2	7.20	12.41	7.10	0.19	24.00	1.16	20.10	6.10	0.43	0.20	6.80	12.70	1.70	0.48

C: carbon; OM: organic matter; pH (H_2O): hydrogenionic potential; EC: electrical conductivity; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; Zn: zinc; B: boron

Table 3 - Description of population densities and spacing of radish and coriander used in the experiments in intercropping and monocropping

Population density of the crops in intercropping (thousand plants ha^{-1})		Spacing (m)	
Radish	Coriander	Radish	Coriander
500	400.000	0.20 × 0.05	0.20 × 0.120 (2 pl)
500	600.000	0.20 × 0.05	0.20 × 0.083 (2 pl)
500	800.000	0.20 × 0.05	0.20 × 0.062 (2 pl)
500	1,000.000	0.20 × 0.05	0.20 × 0.050 (2 pl)
Population density of the crops in monocropping (thousand plants ha^{-1})			
Radish	500.000	0.20 × 0.10	
Coriander	1,000.000		0.20 × 0.05 (1 pl)

* pl – plants

After the solarization period, the material used as green manure was incorporated on October 13, 2021, and October 5, 2022, with the use of hoes. From incorporation to crop harvesting, irrigation was performed daily using a microsprinkler divided into two shifts (morning and afternoon). The amount of water supplied was determined by the values of the radish cultivation coefficient (initial Kc = 0.45; average Kc = 0.95; and final Kc = 0.65), with irrigation depths, when necessary, of approximately 8 mm day^{-1}.

The spontaneous species of the Caatinga, hairy woodrose and roostertree, collected in different areas of the municipality of Mossoró, RN, were used as green manure in the fertilization of radish and coriander. They were collected before the beginning of flowering and after collection, the plants were crushed in forage to obtain particles of 2–3 cm, which were dehydrated at room temperature until reaching 10% humidity and later submitted to laboratory analysis. The chemical compositions obtained in 2021 and 2022 are shown in Table 4.

The radish cultivar planted was 'Crimson Gigante', and the coriander cultivar was 'Verdão'. Both cultivars were recommended by research on monocropping in the northeast region of Brazil (Marsaro *et al*., 2014; Souza *et al*., 2020). Both crops were sown on November 3, 2021, in the first year and on October 27, 2022, in the second year, in holes approximately 3 cm deep with 2–3 seeds per hole and covered with organic substrate. After 7 days of sowing (DAS), the radish was thinned, leaving 1 plant per hole, whereas coriander was thinned at 15 DAS, leaving 2 plants per hole to reach the studied population density.

Weed control was carried out manually whenever necessary. No chemical pest or disease control methods were used. In the first cropping season, coriander and radish were harvested at 30 and 34 DAS, respectively. In the second season, coriander was harvested at 33 days, while radish was harvested at 30 DAS.

The following agronomic characteristics of coriander were evaluated in a sample of 20 plants from the harvest area, chosen at random: plant height (cm), measured from ground level to the tip of the tallest leaves; the number of stems per plant; leaf/stem ratio, obtained from the ratio between the fresh leaf mass and the fresh stem mass; and dry shoot mass, determined by drying in an oven with forced air circulation at 65 °C, until reaching a constant weight and expressed in t ha^{-1}. The green mass yield was obtained from the fresh mass of the aerial part of the plants in the harvest area and expressed in t ha^{-1}, and the number of bunches per m² was calculated from the number of bunches of 100 g obtained from the green mass yield.

For the radish crop, plant height, longitudinal diameter of roots, dry root and shoot mass, and total and commercial productivity of roots were evaluated. The agroeconomic efficiency indices used in the evaluation of the radish and coriander intercropping systems were the system productivity index (SPI), LEC and MER.

The SPI was calculated by the following expression (Chaves *et al*., 2020): $SPI = [(Y_r / Y_c) \times Y_{cr}] + Y_{rc}$ and expressed in t ha^{-1}, where Y_r is the commercial productivity of radish roots; Y_c is the productivity of coriander leaves in monocropping; Y_{cr} is the productivity of coriander leaves intercropped with radish; and Y_{rc} is the commercial productivity of radish roots intercropped with coriander. The main advantage of SPI is that it standardizes the productivity of the secondary crop (coriander) in relation to the main crop (radish).

The LEC was calculated using the following expression (Pinto, Pinto and Pitombeira, 2012): $LEC = LER_r \times LER_c$, where LER_r and LER_c represent the partial land equivalent ratios of radish and coriander, respectively. For intercropping between the two crops, the minimum expected equivalent coefficient is 25%; that is, the yield advantage becomes viable if the LEC value is greater than 0.25.

Table 4 - Chemical analysis of macro- and micronutrients in the dry biomass of hairy woodrose and roostertree incorporated into the soil in radish and coriander intercropping in two cropping seasons

Green manure	N	P	K	Mg	Ca	C:N
	g kg^{-1}					
Cropping season 2021						
M. aegyptia	20.56	2.83	37.08	7.07	19.35	25:1
C. procera	15.14	2.96	24.84	9.20	17.00	27:1
Cropping season 2022						
M. aegyptia	18.55	1.89	38.68	7.03	9.30	25:1
C. procera	14.09	1.54	22.72	13.50	16.30	27:1

The MER was determined by the following expression (Afe; Atanda, 2015): $MER = (GI_{rc} + GI_{cr}) / GI_r$, where GI_{rc} is the gross income of radish in association with coriander; GI_{cr} is the gross income of coriander intercropped with radish; and GI_r is the highest gross income of radish in monocropping, when compared to coriander. This index measures the economic superiority or otherwise of intercropping over most economical monocropping.

A joint analysis of variance on the two cropping seasons was performed on all the characteristics evaluated using SAS software, which fulfilled the assumption that the mean square ratio of the errors of the two cropping seasons should not be greater than 7 (SAS Institute, 2015). In the analysis of the agroeconomic indices, homogeneity of the variances between the cropping seasons was observed, and the average of these indices between the cropping seasons was calculated. Regression analysis was performed for all variables, followed by a procedure for adjusting the response surface as a function of the equitable amounts of hairy woodrose and roostertree biomass incorporated into the soil and the coriander population densities studied, using Table Curve 3D Software (Systat Software, 2021). The F-test was used to verify whether there was a significant difference between the cropping seasons and the cropping systems (intercropping and monocropping).

RESULTS AND DISCUSSION

Coriander crop performance

There were no significant triple interactions between sources of variation, equitable amounts of hairy woodrose and roostertree biomass, coriander population density, or cropping season on the evaluated coriander traits. However, a significant interaction between cropping season and population density of coriander was recorded only for plant height, dry shoot mass and green mass yield of coriander and between cropping season and amount of green manure biomass for the dry shoot mass (Table 5).

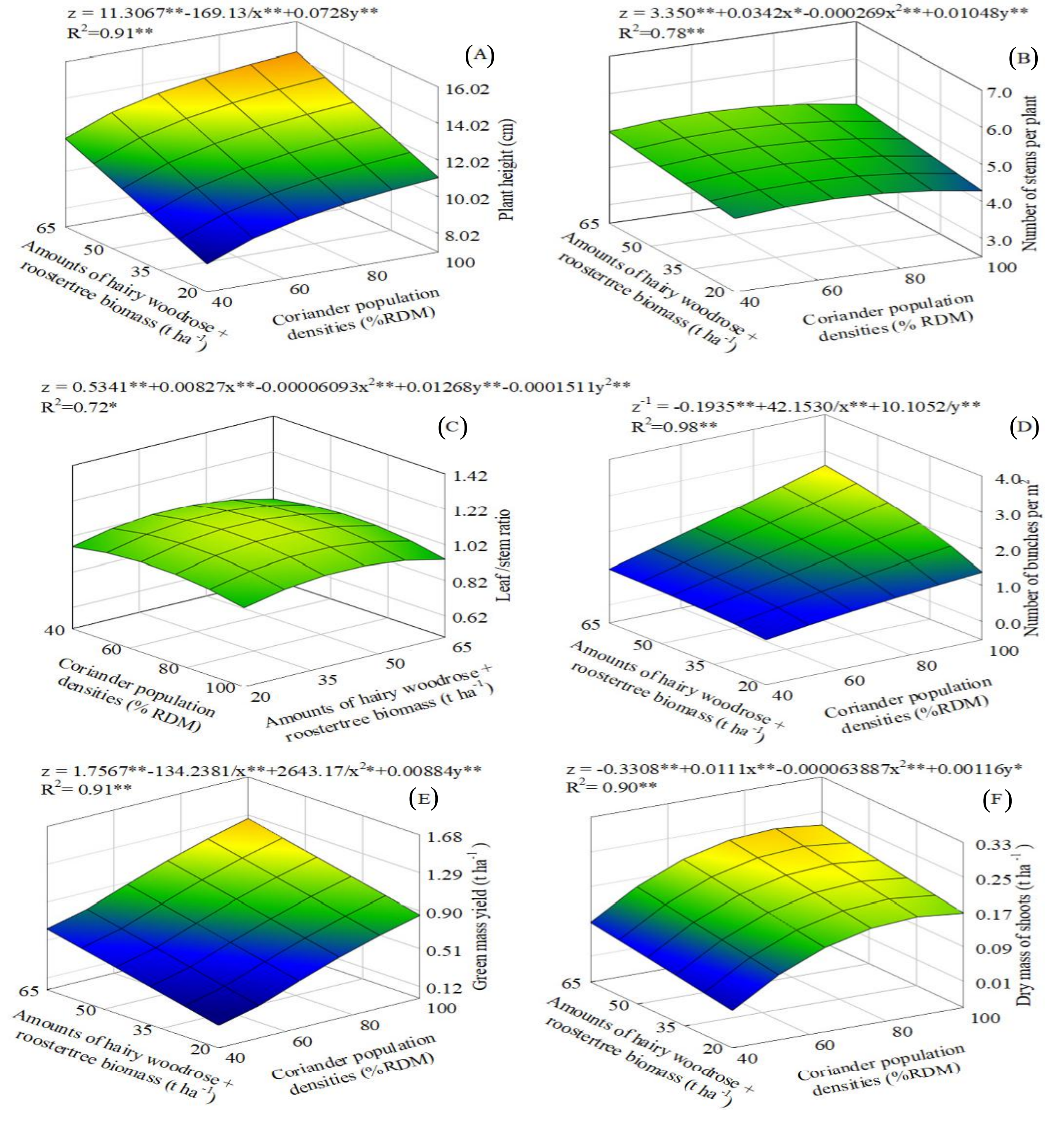
A response surface was fitted for all coriander traits over the cropping seasons as a function of the tested treatment factors (amount of green manure and coriander population density). The maximum optimized values obtained were 14.35 cm for plant height (Figure 1A), 5 stems per plant (Figure 1B), 1.08 for the leaf/stem ratio (Figure 1C), 2.61 bunches per square meter (Figure 1D), 1.25 t ha^{-1} for green mass yield (Figure 1E), and 0.23 t ha^{-1} for dry shoot mass (Figure 1F) in the combinations of equitable amounts of green manure biomass of 65, 65, 42, 65, and 65 t ha^{-1}, respectively, and coriander population densities of 100, 63.5, 67.8, 100, 100, and 87% of RDM.

Table 5 - F values for plant height (PH), dry shoot mass (DMS), number of stems per plant (NSP), leaf/stem (L/S) ratio, green mass yield (GMY) and number of bunches (NB) per m² of coriander intercropped with radish under different equitable amounts of hairy woodrose and roostertree biomass at different coriander population densities in the 2021 and 2022 cropping seasons

Sources of variation	PH		DMS		NSP	L/S	GMY	NB m^{-2}
Blocks (Cropping seasons)	1.45^{ns}		0.26^{ns}		4.55**	0.92^{ns}	2.29^{ns}	0.02^{ns}
Cropping seasons (Y)	2.39*		39.18^{ns}		11.66**	9.97**	97.79**	0.67^{ns}
Amounts of hairy woodrose and roostertree biomass (A)	42.08**		16.33**		3.98*	2.76*	27.66**	0.18^{ns}
Population densities of coriander (D)	28.65**		129.49**		0.29^{ns}	2.16^{ns}	69.67**	0.46^{ns}
Y × A	1.08^{ns}		5.26**		0.09^{ns}	0.25^{ns}	1.39^{ns}	0.01^{ns}
Y × D	15.84**		5.76**		0.53^{ns}	0.18^{ns}	23.96**	0.15^{ns}
A × D	1.43^{ns}		1.28^{ns}		0.98^{ns}	1.61^{ns}	2.13	0.01^{ns}
Y × A × D	0.51^{ns}		1.33^{ns}		1.17^{ns}	0.19^{ns}	0.67^{ns}	0.01^{ns}
Monocropping (M) × Intercropping (I)	16.71**		4.67*		0.73^{ns}	3.2^{ns}	0.80^{ns}	0.05^{ns}
Y × M vs I	35.14**		23.76**		1.55^{ns}	3.26^{ns}	0.90^{ns}	0.04^{ns}
CV (%)	10.66		21.40		15.62	15.41	27.63	30.38
Cropping seasons								
2021					4.93 A	0.95 B	0.59 B	1.18 A
2022					4.47 B	1.04 A	0.90 A	1.74 B
Cropping systems	2021	2022	2021	2022				
Intercropping	11.97 aA	11.40 aA	0.14 bA	0.17 aB	4.70 A	1.00 B	0.75 A	1.46 B†
Monocropping	7.43 bB	10.91 aA	0.09 bB	0.19 aA	4.42 A	1.13 A	0.66 A	1.95 A

*, **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$, and non-significant at $p > 0.05$ by F test; CV – Coefficient of variation. †Means followed by different lowercase letters in the column differ statistically from each other by the F test at a 5% probability level

Figure 1 - Plant height (A), number of stems per plant (B), leaf/stem ratio (C), number of bunches per square meter (D), green mass yield (E), and dry shoot mass (F) of coriander intercropped with radish under different equitable amounts of hairy woodrose and roostertree biomass incorporated into the soil at different coriander population densities



These results showed the use of environmental resources by coriander plants, in which different amounts of green manure incorporated into the soil provided sufficient nutrients for good growth and development in intercropping at the tested population densities, thus establishing different standards of intraspecific and interspecific competition.

Regardless of the competition provided by the coriander population density, 65 t ha^{-1} of biomass from the green manures was responsible for providing a high green mass yield and dry shoot mass of the coriander when intercropped with radish, expressed in growth and culture development. This result showed the efficiency of using organic fertilizers in increasing the productivity of the aerial parts and green mass of plants due to the increase in nutrient availability, thus favoring the physical properties and soil microorganism activity (Alzain, Loutfy and Aboelkassem, 2023).

When intercropping beet with arugula as a function of different amounts of hairy woodrose and roostertree biomass at different arugula population densities in a semi-arid environment, Lino *et al.* (2021) optimized the agronomic characteristics of the leafy crop with the same amount of green manure tested in this study. This demonstrates the efficiency of the green fertilizer biomass of hairy woodrose and roostertree in optimizing the characteristics of leafy crops when intercropped with tuberose.

Significant interactions were recorded between cropping seasons and cropping systems only for plant height and dry shoot mass of the coriander (Table 4). Studying the cropping seasons within each cropping system, the 2022 season exhibited a coriander plant height similar to that of 2021 in the intercropping system and stood out from the 2021 season in the monocropping system. In terms of dry shoot mass, the 2022 season stood out from the 2021 season in both cropping systems. However, when studying the cropping systems within each cropping season, intercropping stood out from monocropping in the 2021 season, both in terms of plant height and dry shoot mass. During the 2022 season, the cropping systems exhibited similar behavior in terms of plant height. The dry shoot mass of the monocropping system stood out from that of the intercropping system (Table 4), and this better performance is probably due to the lower intraspecific competition of coriander compared to the competition of the intercrop (intraspecific plus interspecific).

The number of stems per plant and number of coriander bunches per square meter in the 2021 season stood out from the 2022 cropping season, while the leaf/stem ratio and the green mass yield of coriander in the 2022 season differed significantly from that in the 2021 season. The climatic differences between 2021 (higher temperatures and relative humidity) and 2022 (lower temperatures and relative humidity), together with the tested population densities, were mainly responsible for these differences in the number of stems per plant and number of bunches per square meter.

Comparing the cropping systems, the number of stems per plant and green mass yield were similar between the intercropping and monocropping systems due to the lower intraspecific competition of coriander in monocropping. The monocropping system surpassed the intercropping system for leaf/stem ratio and the number of bunches per square meter (Table 4). The proximity of crops in intercropping predisposes them to interspecific competition, that is, greater competition for light, water, nutrients, oxygen, carbon dioxide and space (Nascimento *et al.*, 2018). This behavior explains the better performance of coriander in monocropping compared to intercropping in this study.

Performance of the radish crop

Analyses of variance of the agronomic characteristics evaluated in radish are shown in Table 6. There were no significant triple interactions between the sources of variation, equitable amounts of hairy woodrose and roostertree biomass, coriander population density, and cropping season on the characteristics evaluated in radish. However, significant interactions were recorded between cropping season and green manure amount for radish plant height and between cropping season and coriander population density for plant height and radish root transversal diameter (Table 6).

Table 6 - F values for plant height (PH), transverse diameter (TD), dry shoot mass (DMS), dry root mass (DMR), commercial productivity (PC), and total productivity (PT) of radish intercropped with coriander under different equitable amounts of hairy woodrose and roostertree biomass at diverse coriander population densities in the 2021 and 2022 cropping seasons

Sources of variation	PH	TD	DMS	DMR	PC	PT
Blocks (Cropping seasons)	8.65**	5.41**	2.48*	6.24**	2.23^{ns}	2.04^{ns}
Cropping seasons (Y)	305.33**	114.09**	2.99^{ns}	0.54^{ns}	5.30*	6.77*
Amounts of hairy woodrose and roostertree biomass (A)	21.88**	2.56^{ns}	39.23**	8.91**	26.94**	26.17**
Population densities of coriander (D)	11.30**	4.21**	3.47*	8.92**	4.48**	2.17^{ns}
Y × A	18.75**	1.41^{ns}	1.44^{ns}	0.54^{ns}	0.72^{ns}	0.70^{ns}
Y × D	4.82**	10.87**	0.41^{ns}	0.14^{ns}	0.66^{ns}	0.54^{ns}
A × D	1.83^{ns}	0.89^{ns}	1.44^{ns}	1.07^{ns}	1.69^{ns}	1.77^{ns}
Y × A × D	0.89^{ns}	0.90^{ns}	0.52^{ns}	0.22^{ns}	0.35^{ns}	0.40^{ns}
Monocropping (M) × Intercropping (I)	17.65**	0.44^{ns}	1.33^{ns}	11.09**	2.82^{ns}	0.27^{ns}
Y × M vs I	18.87**	1.56^{ns}	0.20^{ns}	10.30**	2.68^{ns}	0.42^{ns}
CV (%)	11.51	8.43	15.04	17.17	12.35	9.97

Continuation Table 6

Cropping seasons								
2021			37.92 B	0.52 A			13.70 A	16.57 A
2022			44.45 A	0.49 A			13.02 B	15.82 A
Cropping systems	2021	2022			2021	2022		
Intercropping	22.67 aA	15.93 bA	41.18 A	0.51 A	0.46 aB	0.47 aB	13.36 A	16.19 A
Monocropping	16.63 aB	12.77 bB	42.33 A	0.55 A	0.61 aA	0.59 aA	11.98 A	15.78 A

*, **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$, and non-significant at $p > 0.05$ by F test; CV – Coefficient of variation. †Means followed by different lowercase letters in the column differ statistically from each other by the F test at a 5% probability level

The response surface was adjusted for each radish characteristic over the cropping seasons, where the maximum values reached in plant height and root transverse diameter were 22.57 cm and 42.83 mm, respectively, when 65 t ha^{-1} green manure was incorporated into the soil and a coriander population density of 100% RDM was used (Figure 2A and 2B). However, the maximum value obtained for the dry shoot mass was 0.63 t ha^{-1} with 65 t ha^{-1} of green manure added to the soil and a coriander population density of 100% RDM (Figure 2C). For the dry root mass, this maximum value was 0.55 t ha^{-1} with 65 t ha^{-1} hairy woodrose and roostertree at a coriander population density of 40% RDM (Figure 2D).

For commercial productivity, the maximum value obtained was 14.90 t ha^{-1} when 65 t ha^{-1} of green manure was incorporated into the soil and a coriander population density of 100% RDM was used (Figure 2E). For total productivity, the maximum value reached was 18.81 t ha^{-1} with 65 t ha^{-1} of hairy woodrose and roostertree and a coriander population density of 55% RDM (Figure 2F).

Based on these results for the characteristics evaluated in radish, the best combination of green manure biomass amount and coriander population density was registered at 65 t ha^{-1} of hairy woodrose and roostertree, regardless of the population density. These results are related to the nutritional contribution due to the efficiency of the highest dose of green manure, resulting in good crop growth and development. However, it is known that an adequate nutrient supply incorporated into the soil can promote the good growth and vegetative development of crops, the expansion of the photosynthetic area, and the activation and increase of the crop production potential (Favacho *et al*., 2017). According to Fontanetti *et al*. (2006), the absorption of nutrients resulting from the mineralization of green manure by vegetables depends largely on the synchrony between the decomposition and mineralization of plant residues and the moment of greatest demand for each crop.

When intercropping radish with lettuce as a function of different amounts of hairy woodrose and roostertree biomass at different lettuce population densities in a semi-arid environment, Lino *et al*. (2022) optimized the agronomic characteristics of tuberose in the same amount of green manure tested in this study. This result demonstrates the efficiency of green manure biomass in optimizing these radish characteristics when intercropped with lettuce.

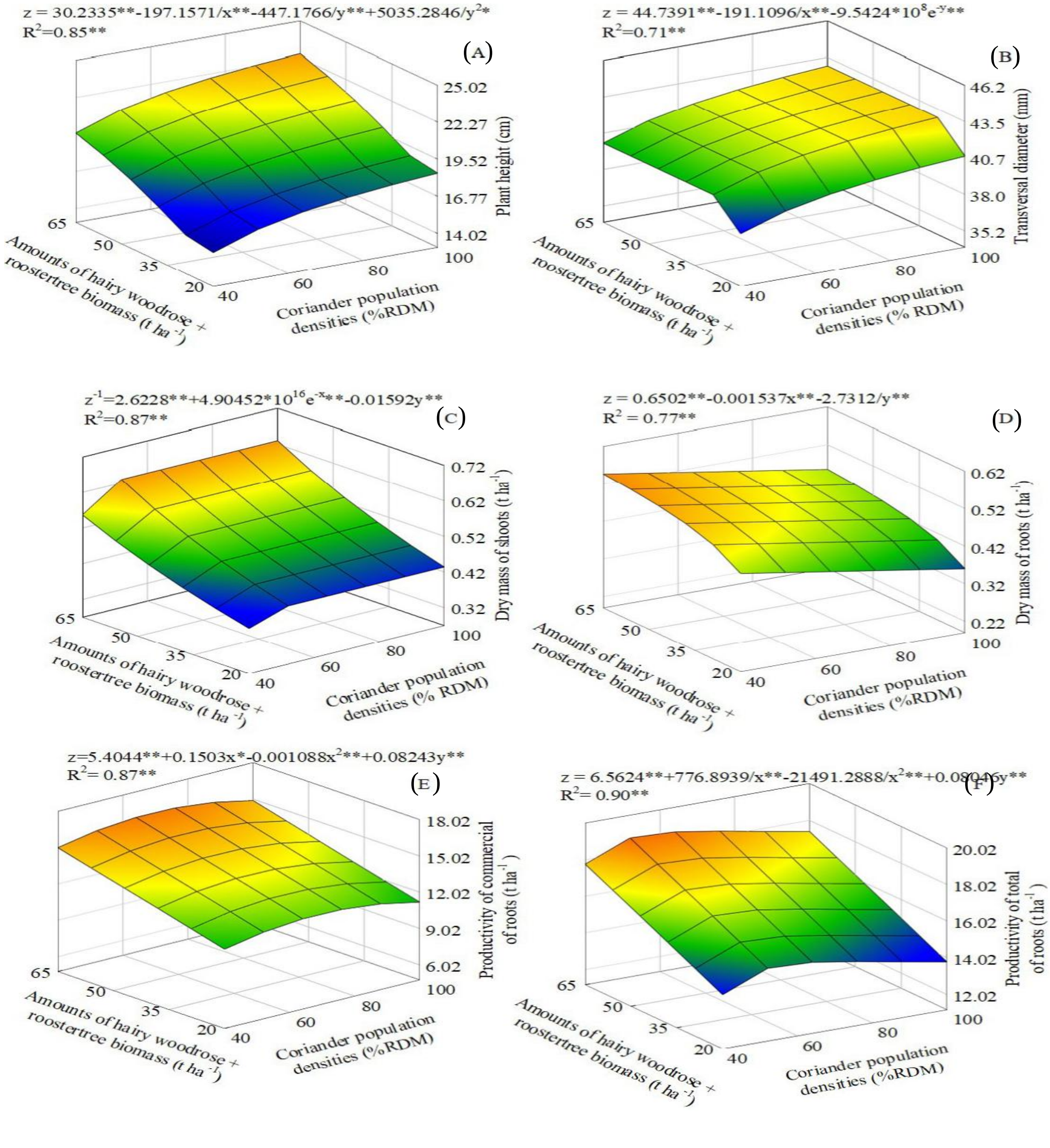
Significant interactions were recorded between cropping seasons and cropping systems for plant height and dry root mass of radish (Table 5). Studying the cropping seasons within each cropping system, the plant height in the 2021 season stood out from that of 2022, both in the intercropping and monocropping systems, while the dry root mass was similar in the two seasons for each cultivation system. However, when studying the cropping systems within each cropping season, it was observed that intercropping outperformed monocropping in both seasons in terms of plant height, while the dry root mass of monocropping surpassed intercropping in both crop seasons (Table 5).

The transverse diameter of radish roots in the 2022 cropping season stood out from the 2021 cropping season, while the commercial productivity of radish roots in the 2021 season differed significantly from that of the 2022 season, probably due to the competitive pressure exerted by the coriander population density of 100% RDM. No significant differences were observed in the dry shoot mass or total productivity of radish roots between the cropping seasons (Table 5). However, no significant differences were observed in the transverse diameter, dry shoot mass, commercial productivity or total productivity of radish roots between cropping systems (intercropping and monocropping) (Table 5).

Agronomic and monetary indicators

Significant interactions between the studied treatment factors, equitable amounts of hairy woodrose and roostertree biomass, and coriander population densities were not recorded for the agronomic and monetary indicators of the intercropping system, namely SPI, LEC and MER (Table 7).

Figure 2 - Plant height (A), transverse diameter (B), dry shoot mass (C), dry root mass (D), commercial productivity (E) and total productivity (F) of radish intercropped with coriander under different equitable amounts of hairy woodrose and roostertree biomass incorporated into the soil at different coriander population densities



However, a response surface was fitted for each agroeconomic indicator (Figure 3). The maximum values reached for SPI, LEC and MER were 7.56 t ha^{-1}, 0.33 and 0.98 with equitable amounts of green manure biomass of 65, 43 and 65 t ha^{-1}, respectively, at a coriander population density of 100% RDM (Figure 3A, 3B and 3C).

The results of the agronomic and monetary indicators obtained with different equitable amounts of hairy woodrose and roostertree biomass are due in part to the good nutritional support provided by the green manure mixture, which were able to efficiently meet the needs of the crops and express their productive potential in a high-density situation. Green manure obtained from the biomass of regional plants not only increases the organic matter and nutrient content in the soil but also improves the structure, aeration and water storage capacity in the soil, thus contributing to the chemical balance and physical and biological properties of the soil (Silva *et al.*, 2020). Tavella *et al.* (2010) showed that green manure can cycle nutrients in the soil, bringing nutrients that are at a greater depth to the surface.

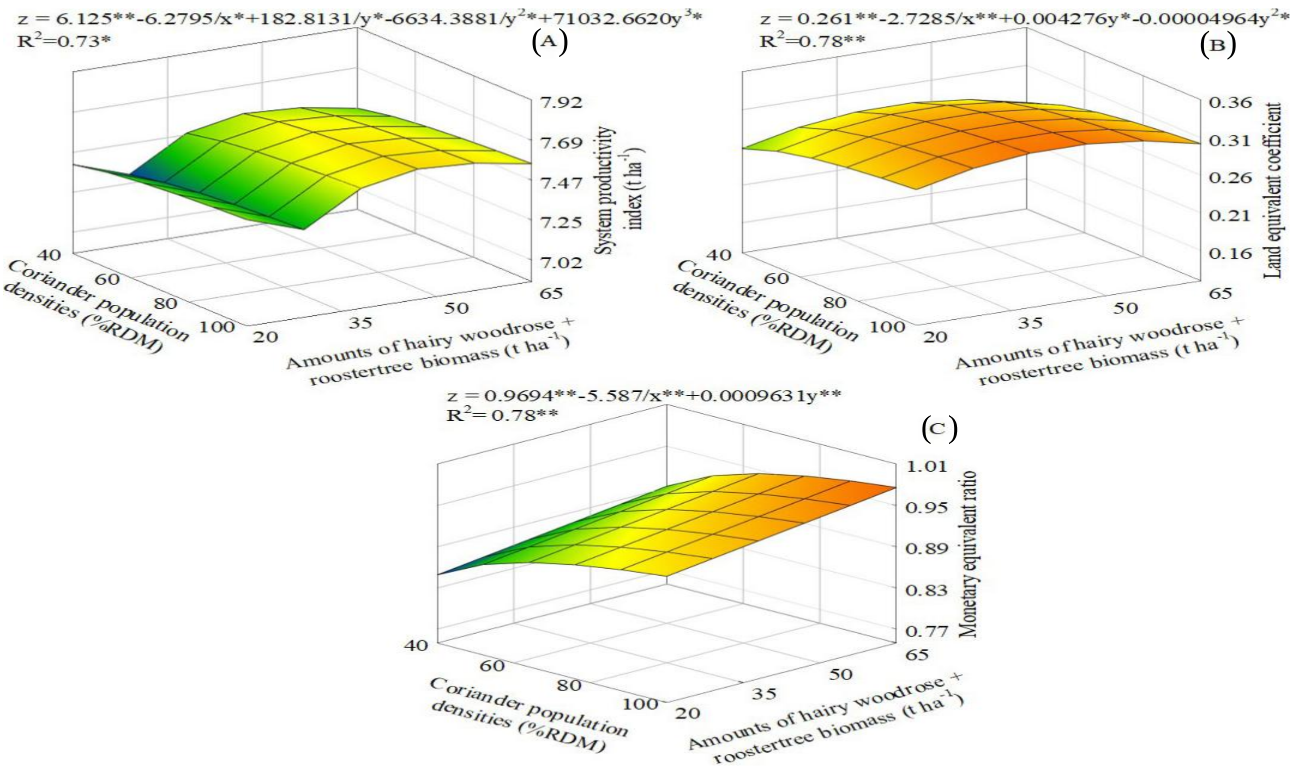
These results also indicate that the use of a high population density for coriander (secondary crop) did not result in a negative effect in the intercropping system with radish, mainly in terms of competitive pressure for solar radiation, nutrients and other environmental resources. This shows that the plant population in intercropping systems depends on crop type, growth habit, soil fertility, water and other factors necessary for growth (Balasubramaniyan and Palaniappan, 2016). In the case under study, the architecture and morphology of radish and coriander crops completely differed with regard to the demand for environmental resources, as they demand their needs at different times and in different occupied spaces.

Table 7 - F values for the system productivity index (SPI), land equivalent coefficient (LEC) and monetary equivalence ratio (MER) of radish intercropped with coriander under different equitable amounts of hairy woodrose and roostertree biomass at different coriander population densities

Sources of variation	SPI	LEC	MER
Blocks	14.14**	1.76ns	1.01ns
Amounts of hairy woodrose and roostertree biomass (A)	5.64*	5.40**	5.63**
Population densities of coriander (D)	1.66ns	1.58ns	1.67ns
A x D	1.38ns	1.38ns	1.37ns
CV (%)	6.74	39.25	20.43

*, **, ns - Significant at $p \leq 0.05$ and at $p \leq 0.01$, and non-significant at $p > 0.05$ by F test; CV – Coefficient of variation

Figure 3 - System productivity index (A), land equivalent coefficient (B), and monetary equivalent ratio (C) of radish intercropped with coriander under different equitable biomass amounts of hairy woodrose and roostertree incorporated into the soil and at different coriander population densities



The highest SPI (7.86 t ha^{-1}) and LEC (0.43) were obtained with 24 and 20 t ha^{-1} of the green manure biomass mixture, respectively, and 100% RDM, demonstrating the agronomic efficiency of the intercropping system of radish and coriander in relation to the monocropping system of these crops. Diniz *et al*. (2017) found that when the LEC value was greater than 0.25, the intercropping system had a production advantage over monocropping.

Based on an MER value of 1.08, the agronomic efficiency of radish–coriander intercropping was translated into monetary terms. According to Afe and Atanda (2015), when the MER is greater than 1.0, intercropping systems are considered more profitable than monocropping systems. This superiority of MER can be attributed to the complementary nature of the crops involved. The results obtained corroborate those obtained by Lino *et al*. (2022), who intercropped radish with different lettuce population densities in the same region as the present study and obtained an SPI of 15.37 t ha^{-1}, LEC of 1.27 and MER of 1.30, with 65 t ha^{-1} biomass with equitable amounts of hairy woodrose and roostertree green manure and a population density of 300,000 lettuce plants per hectare.

CONCLUSIONS

1. The greatest agronomic and monetary advantages of intercropping radish and coriander were obtained with a LEC of 0.42 and MER of 0.76, with hairy woodrose and roostertree biomass amounts of 20 and 39 t ha^{-1} added to the soil and a coriander population density of 100% RDM.
2. The green mass yield of coriander and the commercial productivity of radish roots optimized in the intercropping system were 1.25 and 14.90 t ha^{-1} when fertilized with 65 t ha^{-1} of green manure biomass at a coriander population density of 100% RDM;
3. The use of hairy woodrose and roostertree biomass from the Caatinga ecosystem proved to be a viable option for producers who practiced the intercropping of radish and coriander in a semi-arid environment.

REFERENCES

AFE, A. I.; ATANDA, S. Percentage yield difference, an index for evaluating intercropping efficiency. **Journal of Experimental Agriculture International**, v. 5, n. 5, p. 459-465, 2015.

ALZAIN, M. N.; LOUTFY, N.; ABOELKASSEM, A. Effects of different kinds of fertilizers on the vegetative growth, antioxidative defense system and mineral properties of sunflower plants. **Sustainability**, v. 15, n. 13, p. 1-13, 2023.

BALASUBRAMANIYAN, P.; PALANIAPPAN. **Principles and practices of agronomy**. Jodhpur, India: Agrobios, 2016.

BECK, H. E. *et al*. Data descriptor: present and future Köppen-Geiger climate classification maps at 1-km resolution. **Scientific Data**, v. 5, n. 1, p. 1-12, 2018.

BURGESS, A. J.; CANO, M. E. C.; PARKES, B. The deployment of intercropping and agroforestry as adaptation to climate change. **Crop and Environment**, v. 1, n. 2, p. 145-160, 2022.

CHAVES, A. P. *et al*. Cowpea and beet intercropping agro-economic dynamics under spatial arrangement and cowpea population density. **Horticultura Brasileira**, v. 38, n. 2, p. 192-203, 2020.

DINIZ, W. J. S. *et al*. Forage cactus-sorghum intercropping at different irrigation water depths in the Brazilian Semiarid Region. **Pesquisa Agropecuária Brasileira**, v. 52, n. 9, p. 724-733, 2017.

FAVACHO, F. S. *et al*. Productive and economic efficiency of carrot intercropped with cowpea-vegetable resulting from green manure and different spatial arrangements. **Revista Ciência Agronômica**, v. 48, n. 2, p. 337-346, 2017.

FONTANÉTTI, A. *et al*. Adubação verde na produção orgânica de alface americana e repolho. **Horticultura Brasileira**, v. 24, n. 2, p. 146-150, 2006.

LABORATÓRIO DE INSTRUMENTAÇÃO, METEOROLOGIA E CLIMATOLOGIA. **Estação Meteorológica Automática (EMA)**. Mossoró: Universidade Federal Rural do Semi-Árido, 2022. Disponível em: https://usinasolar.ufersa.edu.br/dados-emas/. Acesso em: 4 out. 2022.

LINO, F. K. K. S. *et al*. Agroeconomic benefits in radish-lettuce intercropping under optimized green manuring and planting density. **Horticultura Brasileira**, v. 40, n. 3, p. 302-310, 2022.

LINO, V. A. S. *et al*. Beet-arugula intercropping under green manuring and planting density induce to agro-economic advantages. **Horticultura Brasileira**, v. 39, n. 4, p. 432-443, 2021.

LIU, Y. *et al*. Effects of intercropping on safe agricultural production and phytoremediation of heavy metal-contaminated soils. **Science of the Total Environment**, v. 875, 162700, 2023.

MARSARO, R. *et al*. Produção de cultivares de coentro em diferentes telados e campo aberto. **Cultivando o Saber**, v. 7, n. 4, p. 362-373, 2014.

NASCIMENTO, C. S. *et al*. Effect of population density of lettuce intercropped with rocket on productivity and land-use efficiency. **Plos One**, v. 13, n. 4, p. 1-14, 2018.

OLIVEIRA, J. R. *et al*. **Avaliação agroeconômica das culturas de rabanete e coentro em função da época de estabelecimento do consórcio**. 2019. Trabalho de Conclusão de Curso (Graduação em Agroecologia) – Universidade Federal do Recôncavo da Bahia, Cruz das Almas, BA, 2019. Disponível em: http://www.repositoriodigital.ufrb.edu.br/bitstream/12345 6789/1637/1/TCC%20-%20 Final%20 pdf.pdf. Acesso em: 24 maio 2023.

OLIVEIRA, L. J. *et al*. Viability of polycultures of arugula-carrot-coriander fertilized with hairy woodrose under different population densities. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 21, n. 9, p. 611-617, 2017.

PINTO, C. M.; PINTO, O. R. O.; PITOMBEIRA, J. B. Mamona e girassol no sistema de consorciação em arranjo de motivadores: habilidade competitiva. **Revista Brasileira de Agropecuária Sustentável**, v. 2, n. 2, p. 103-113, 2012.

RABELO, J. da S. *et al.* Agronomic preliminary performance of two radish cultivars intercropped with coriander. **Journal of Agricultural Science**, v. 11, n. 18, p. 173-178, 2019.

RIBEIRO, G. M. *et al.* Productive performance of carrot and cowpea intercropping system under different spatial arrangements and population densities. **Revista Caatinga**, v. 31, n. 1, p. 19-27, 2018.

SÁ, J. M. *et al.* Agro-economic efficiency in radish-arugula intercropping as a function of green manuring and population density. **Research, Society and Development**, v. 10, n. 5, e5310514867, 2021.

SÁ, J. M. *et al.* Yield performance and agro-economic efficiency of radish-arugula intercropping under green manuring and planting density. **Horticultura Brasileira**, v. 40, n. 2, p. 44-56, 2022.

SANTOS, H. G. *et al.* **Sistema brasileiro de classificação de solos**. 5. ed. rev. e ampl. Brasília, DF: Embrapa, 2018. 356 p.

SAS INSTITUTE. **SAS/IML® 14.1 user's guide**. Cary, NC: SAS Institute, 2015.

SILVA, J. N. *et al.* Production and benefits in carrot and vegetable cowpea associations under green manuring and spatial arrangements. **Revista Ciência Agronômica**, v. 51, n. 4, e20197067, 2020.

SOUZA, L. G. S. *et al*. Desempenho de cultivares de rabanete em sistema orgânico no Acre. **Scientia Naturalis**, v. 2, n. 2, p. 536-542, 2020.

SYSTAT SOFTWARE. **Table curve 3D Academic Edition**. San Jose, CA: Systat Software, 2021.

TAVELLA, L. B. *et al*. Cultivo orgânico de coentro em plantio direto utilizando cobertura viva e morta adubado com composto. **Revista Ciência Agronômica**, v. 41, n. 4, p. 614-618, 2010.

YADAV, A. S.; SINGH, S. P. Soil solarization: sustainable tool for insect-pest and weed management. *In*: PANT, H. *et al*. **Emerging trends in agricultural, environmental and rural developmental challenges and solution**: an overview. India: Society of Biological Sciences and Rural Development, 2017. p. 225-238.