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Lettuce and arugula production in intercropping and organic fertilization

Produção de alface e rúcula em cultivo consorciado e adubação orgânica

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ABSTRACT - Compared to monoculture, vegetable intercropping allows the optimization of environmental resources and inputs, with positive effects on the yield and profitability of the crop. This study aimed to evaluate the yield of lettuce and arugula in intercropping and intercrop evaluation indexes according to cattle manure doses. The experiment was conducted in Aquidauana, MS, Brazil. Five doses of cattle manure (0, 15, 30, 45, and 60 t ha^{-1}) were evaluated with four replications in a randomized block design. Higher growth and yield of the intercropped species were observed when the intercrop received 60 t ha^{-1} of cattle manure. However, the maximum values of the variables were not reached, so better performances can be obtained with higher doses. The indexes of actual yield loss and advantage of intercropping presented higher values starting at doses of 26 and 30 t ha^{-1} of manure, respectively. The highest land use efficiency (1.28) was obtained with 60 t ha^{-1} of cattle manure, indicating the agronomic viability of the lettuce and arugula intercrop when fertilized only with cattle manure.

Keywords: *Lactuca sativa* L. *Eruca sativa* L. Agronomic performance. Cultivation systems.

RESUMO - Comparado à monocultura, o consórcio de hortaliças possibilita otimizar os recursos ambientais e insumos, com reflexos positivos sobre a produtividade e rentabilidade do cultivo. O objetivo deste estudo foi avaliar a produtividade da alface e rúcula em cultivo consorciado e índices de avaliação de consórcios em função de doses de esterco bovino. O experimento foi realizado em Aquidauana, MS, Brasil. Foram avaliados cinco doses de esterco bovino (0, 15, 30, 45 e 60 t ha^{-1}), em delineamento experimental de blocos casualizados, com quatro repetições. Maior crescimento e produtividade das espécies consorciadas foram observados quando o consórcio recebeu 60 t ha^{-1} de esterco bovino. Porém, não foram alcançados os máximos valores das características e, portanto, melhores desempenhos podem ser obtidos com doses mais elevadas. Os índices perda real de produtividade e vantagem do consórcio apresentaram maiores valores a partir das doses de 26 e 30 t ha^{-1} de esterco, respectivamente. A maior eficiência no uso da terra (1,28) foi obtida com 60 t ha^{-1} de esterco bovino, indicando a viabilidade agronômica do consórcio de alface e rúcula quando adubado somente com esterco bovino.

Palavras-chave: *Lactuca sativa* L. *Eruca sativa* L. Performance agronômica. Sistemas de cultivo.

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INTRODUCTION

Intercropping is a secular practice by small farmers, often in tropical regions (VIEIRA et al., 2012). It is characterized by one or more crops that exploit spatial and/or temporal complementarity, with the possibility of better exploitation of environmental resources and inputs (CARLOS et al., 2021).

The technique shows promise in the environmental sense, however, for the producer to adopt this system, it must also be advantageous in the economic issue (MARTIN-GUAY et al., 2018), as proven by Cecílio Filho et al. (2021) and Sá et al. (2022) through economic indicators.

Organic vegetables have positively moved the market, as bilateral interests (consumer and producer) are met with profitable production (WU et al., 2019), better quality to human health, and lower environmental impact. Lettuce (*Lactuca sativa*) and arugula (*Eruca sativa*) are two of the main leafy vegetables commercialized in Brazil and can be cultivated in intercrops due to architectural differences, periods of demand for environmental resources, and crop cycles. These aspects are important since when there is agronomic compatibility of intercrops; there are positive biological interactions, providing increased yield (CHAVES et al., 2022).

Nascimento et al. (2018) have proven the intercropping of lettuce and arugula. When evaluating lettuce population density, they found higher intercropping efficiency (41%) than single crops. Nascimento, Nascimento and Cecílio Filho (2018) evaluated the spacing and growing season of lettuce intercropped with arugula, and they verified higher profitability during the summer. Bezerra Neto et al. (2012) evaluated the economic and agronomic indexes of lettuce-arugula combined with carrot. The authors found that polyculture was more profitable. The studies found on lettuce-arugula intercropping were conducted in conventional cultivation systems, i.e., non-organic. No studies were found on the intercropping of lettuce and arugula in organic cultivation systems that used manure as a source of organic material.

It is of utmost importance to adhere to strategies for sustainable production, inserting ecological practices to crops that contribute to food security (DUMONT et al., 2019). In addition to providing nutrients to plants (PRADO et al., 2022), the use of organic sources provides several benefits, such as improving the physical, chemical, and biological attributes of the soil, in addition to increasing the water holding capacity (SEDIYAMA et al., 2016), and the additional supply of micronutrients to the soil.

Using cattle manure is an ancient practice of soil fertilization in a sustainable way. However, manure must be managed in the appropriate amount according to the needs of each crop (PRADO et al., 2022) because excessive use can result in environmental impacts such as those caused by synthetic fertilizers, such as soil, air and water contamination, the input of heavy metals and emission of harmful gases (LORENZ; LAL, 2016). Also, being a source of nutrients, it affects the nutritional status of crops harming yield (ZHAO; LI; JIANG, 2019). Thus, it is necessary to study manure doses (AL-GAADI; MADUGUNDU; TOLA, 2019) since increasing doses of manure will not provide continued increments in the intercropping yield.

This study aimed to evaluate the yield of lettuce and arugula grown in intercropping according to cattle manure doses.

MATERIAL AND METHODS

Characterization of the experimental site

The experiment was conducted from September 18 to November 2, 2016, at the State University of Mato Grosso do Sul in Aquidauana, a Cerrado-Pantanal ecotone region.

According to the Köppen classification, the regional climate is *Aw* type (Tropical with a dry season in winter and rainy in summer), with average annual rainfall and maximum and minimum average temperatures of 1200 mm, 33°C, and 19°C, respectively. During the experimental period, there was 232.4 mm of rainfall; the average maximum and minimum temperatures were 39°C and 12°C, respectively. The relative humidity varied from 24 to 93 %. The soil was classified as Argissolo Vermelho, with sandy loam textural class (SCHIAVO et al., 2010).

Treatments and experimental design

Five doses of cattle manure were evaluated (0, 15, 30, 45, and 60 t ha^{-1}), with the amounts corrected to dry base, after drying the manure in an oven with forced air circulation at 65 ºC. The experimental design was randomized blocks with four replications. Each block had experimental units with single crops of lettuce and arugula, corresponding to the control treatment of each species. The total area of each plot was 1.44 m^2 (1.2 x 1.2 m), with the useful area (0.64 m^2) for data collection corresponding to the 16 central lettuce and arugula plants between these rows (Figure 1).

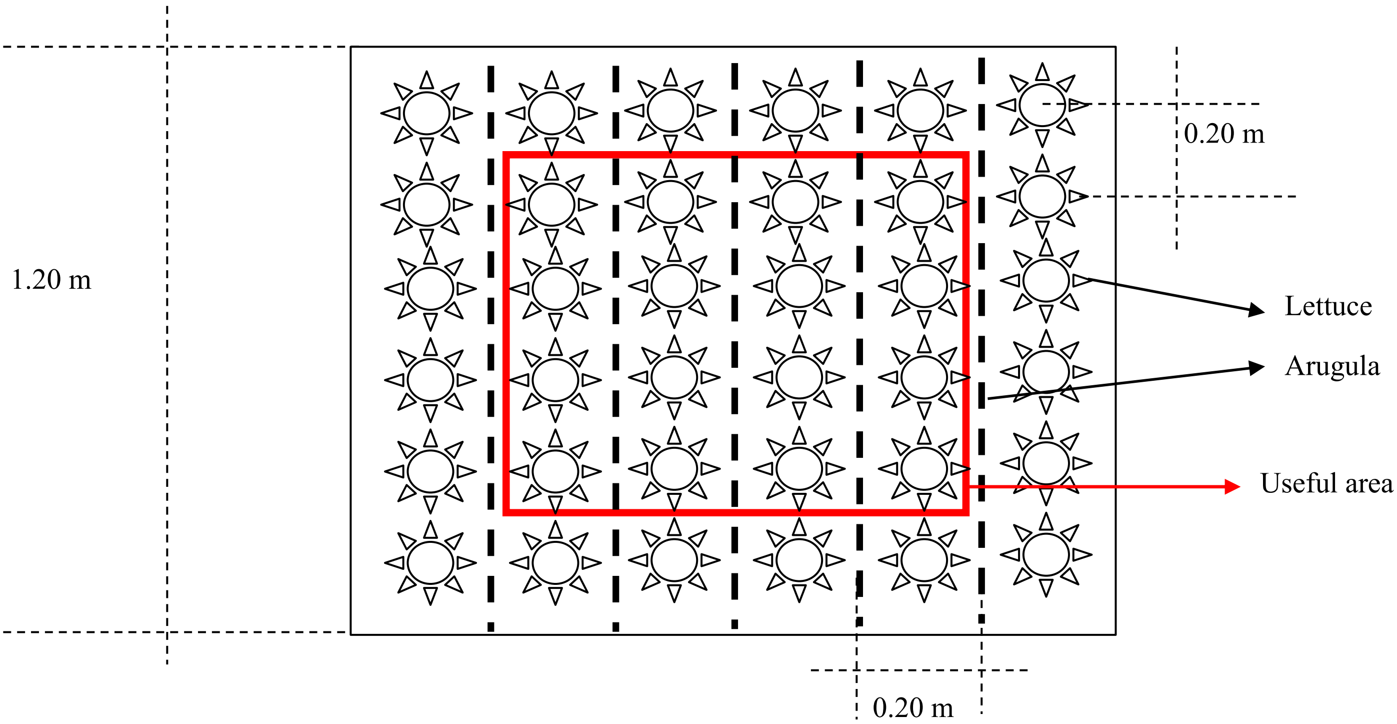

Figure 1. Sketch of the experimental unit with lettuce and arugula intercropped.

Installation and conduction of the experiment

Before the installation of the experiment, soil samples were taken from 0 to 20 cm depth, and the attributes were evaluated according to the methodologies described by Silva (2009). The results obtained were: pH in $CaCl_2$ = 5.5; P resin = 68 mg dm^{-3}; K = 2 $mmol_c$ dm^{-3}; Ca = 74 $mmol_c$ dm^{-3}; Mg = 26 $mmol_c$ dm^{-3}; Al = 0 $mmol_c$ dm^{-3}; H+Al = 22 $mmol_c$ dm^{-3}; Cu = 1.1 mg dm^{-3}; Fe = 104.6 mg dm^{-3}; Mn = 43.8 mg dm^{-3}; Zn = 9.5 mg dm^{-3}; B = 0.23 mg dm^{-3}; S= 5 mg dm^{-3}; and organic matter = 34 g dm^{-3}.

Beds were prepared, and 10 days before planting, manure was incorporated into the 0-0.20 m soil layer, according to the dose recommended in the treatment. For the intercropping, the fertilization corresponded to the treatments. In pre-transplanting lettuce and sowing arugula for single crops, fertilization was performed with 100 g m^{-2} of 4-14-8 (N-P_2O_5-K_2O) (TRANI; PASSOS; AZEVEDO FILHO, 1997). For the topdressing fertilization, 3 g m^{-2} of N (urea) was applied at 10, 20, and 30 days after lettuce transplanting and sowing of arugula. Both in single and intercropping with arugula, 'Solaris' lettuce seedlings were transplanted at 0.20 x 0.20 m spacing. On the same day, the arugula 'Folha Larga' was sown in the middle of the lettuce rows, in the longitudinal direction of the bed. After thinning, performed eight days after emergence, the spacing was 0.20 x 0.05 m. Irrigation was by sprinkler irrigation, with a flow of 2.87 m^3 h^{-1} and a service pressure of 30 m wc., with a daily irrigation schedule divided into two applications (morning and afternoon). The harvest was performed 45 days after planting the species.

Evaluated characteristics

For lettuce, the following were evaluated: (a) height (cm), which was measured with the aid of a graduated ruler, from soil level to the tip of the highest leaf; (b) shoot diameter (cm), which was measured with the aid of a graduated ruler; (c) shoot dry mass (g $plant^{-1}$), which was obtained by drying the leaves and stem in an air forced circulation oven at 65°C, until a constant mass was obtained, and weighed; and (d) yield (t ha^{-1}), which was obtained by adding the fresh masses of the shoot of the plants and estimated for 1 ha.

For arugula plants, in addition to height, shoot dry mass, and yield, as described for lettuce, the number of leaves longer than 3 cm was counted.

To evaluate the consortium, the indices were calculated:

a) Land equivalent ratio (LER), defined by Willey and Osiru (1972), according to the formula:

LER = (Yli/Yls) + (Yai/Yas), where Yli is the yield of lettuce intercropped with arugula, Yls is the yield of single lettuce, Yai is the yield of arugula intercropped with lettuce, and Yas is the yield of single arugula. The indexes for each dose of manure were obtained by considering the value of the average of the replications of the single crops of the respective dose, as recommended by Federer (2002). This standardization was used to avoid difficulties with the possibility of having a complex distribution of the sum of the quotients that define the LER and, thus, the analysis of variance of these indexes not being representative, leading to errors related to the validity of the assumptions of normality and homogeneity. In addition, it was also used to allow validation of the significance tests and the fitted models and, consequently, comparisons between the lettuce and arugula intercropping systems.

b) actual yield loss index (AYL), calculated according to the following formula (BANIK, 1996):

AYL = AYLl + AYLa, where: AYLl = [{(Yli / Zla) / (Yll / Zll)} - 1] and AYLa = [{(Yai / Zal) / (Yaa / Zaa)} - 1].

AYLl and AYLa correspond to the actual yield losses of lettuce and arugula. Zll and Zaa correspond to the proportions of lettuce (1.0) and arugula (1.0) single crop planting, respectively. Zla and Zal correspond to the proportions in which lettuce (6 crop rows) and arugula (5 crop rows) appear in the intercropping, which were 0.55 and 0.45, respectively. Yli corresponds to the yield of lettuce in the intercrop with arugula, and Yai corresponds to the yield of arugula intercropped with lettuce. Yll and Yaa correspond to the yield of lettuce and arugula alone, respectively.

c) intercropping advantage index: (IAI), calculated using the following formula (BANIK et al., 2000):

IAI = IAIl + IAIa, where IAIl = PRRa x Pl and IAIa = PRRr x Pa. Pl is the price of lettuce, R$ 1.50 per kg, and Pa is the price of arugula, R$ 2.50 per kg, for July 2022. The values of the vegetables were obtained at Ceagesp (CEAGESP, 2022), deducting 30%, corresponding to the producer's expenses with packaging, freight, loading and unloading, special rural social security contribution (SRSSC), and commissions.

Statistical Analysis

The data were submitted to the analysis of variance and t-test ($p < 0.05$). Regression analysis was performed for manure doses, and the equation with biological logic of the variable, significant F value, and high determination coefficient was selected. The statistical programs Agroestat (BARBOSA; MALDONADO JÚNIOR, 2015) and Table Curve 3D (Systat Software Inc., 2021) were used.

RESULTS AND DISCUSSION

According to the results presented in Tables 1 and 2, increasing the cattle manure doses positively affected the biometric and yield characteristics of lettuce and arugula intercropping, except for the number of arugula leaves.

For both species, the characteristics responded positively to the amount of manure (Figures 2 and 3). With the highest dose of manure, the height, diameter, shoot dry mass, and lettuce yield were 25, 16, 90, and 70% greater than the values obtained without the application of manure (Figure 2). For single arugula, increases of 54, 70, and 95% were observed for height, shoot dry mass, and yield, respectively, compared to arugula that did not receive manure fertilization (Figure 3).

Table 1. Summary of variance analysis (F values and significance), polynomial regression study and t test for height (cm), shoot diameter (cm), shoot dry mass (SDM, g plant^{-1}) and yield (g m^{-2}) of lettuce as a function of cattle manure dose.

	Height	Diameter	SDM	Yield
	F test			
Cattle manure dose	3.11*	13.50**	5.21**	9.13**
Polynomial regression	**	**	**	**
C.V. (%)	11.12	5.47	23.16	15.02
	T test			
Intercrop. - 0 t ha^{-1}	11.25**	17.70**	3.32**	670.63**
Intercrop. - 15 t ha^{-1}	12.07**	16.98**	4.07**	667.19**
Intercrop. - 30 t ha^{-1}	13.75^{ns}	21.00ns	4.21**	706.25**
Intercrop. - 45 t ha^{-1}	12.95**	17.80**	4.15**	750.00**
Intercrop. - 60 t ha^{-1}	14.40^{ns}	20.80ns	6.43**	1085.31ns
Single cultivation	16.30	23.20	12.77	1606.25

**, * and ^{ns} correspond to significant by F test and t test at 1 and 5% probability, and not significant ($p > 0.05$), respectively.

Table 2. Summary of variance analysis (F values and significance), polynomial regression study and t test for height (cm), number of leaves (leaves per pant), shoot dry mass (SDM, g plant^{-1}) and yield (g m^{-2}) of arugula as a function of cattle manure dose.

	Height	Number of leaves	SDM	Yield
	F test			
Cattle manure dose	5.54**	1.49^{ns}	5.92**	7.53**
Polynomial regression	**	ns	**	**
C.V. (%)	14.34	11.20	18.37	19.73
	t test			
Intercrop. - 0 t ha^{-1}	8.95**	6.47**	0.53**	191.00**
Intercrop. - 15 t ha^{-1}	10.32**	6.60**	0.63**	200.23**
Intercrop. - 30 t ha^{-1}	11.20**	7.00**	0.63**	300.50**
Intercrop. - 45 t ha^{-1}	12.90ns	7.67ns	0.75**	341.31**
Intercrop. - 60 t ha^{-1}	13.73ns	7.15**	0.93**	341.83**
Single cultivation	14.45	9.00	1.63	493.04

** and ^{ns} correspond to significant by F test and t test at 1% probability and not significant ($p > 0.05$), respectively.

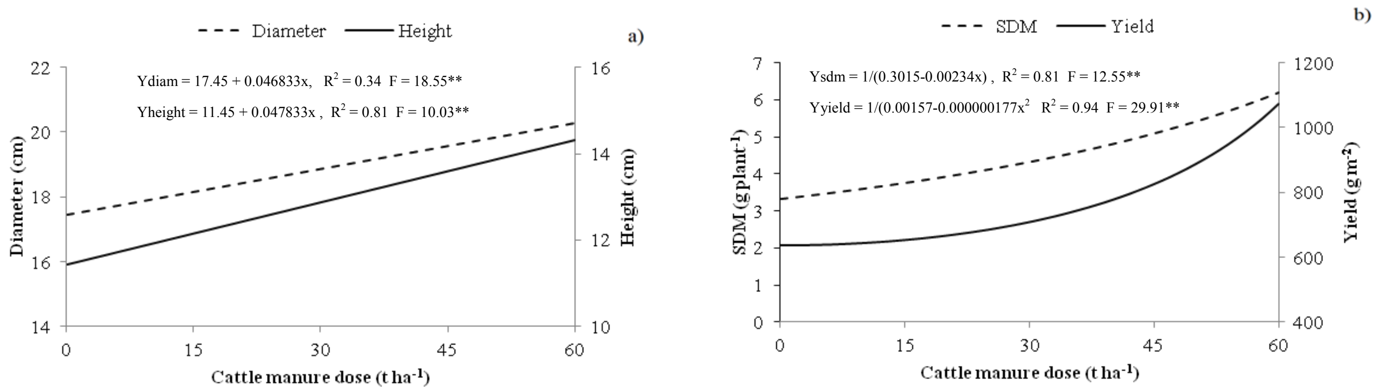

Figure 2. Shoot diameter and height (a), shoot dry mass (SDM) and yield of the lettuce (b) in intercropping with arugula as a function of cattle manure dose.

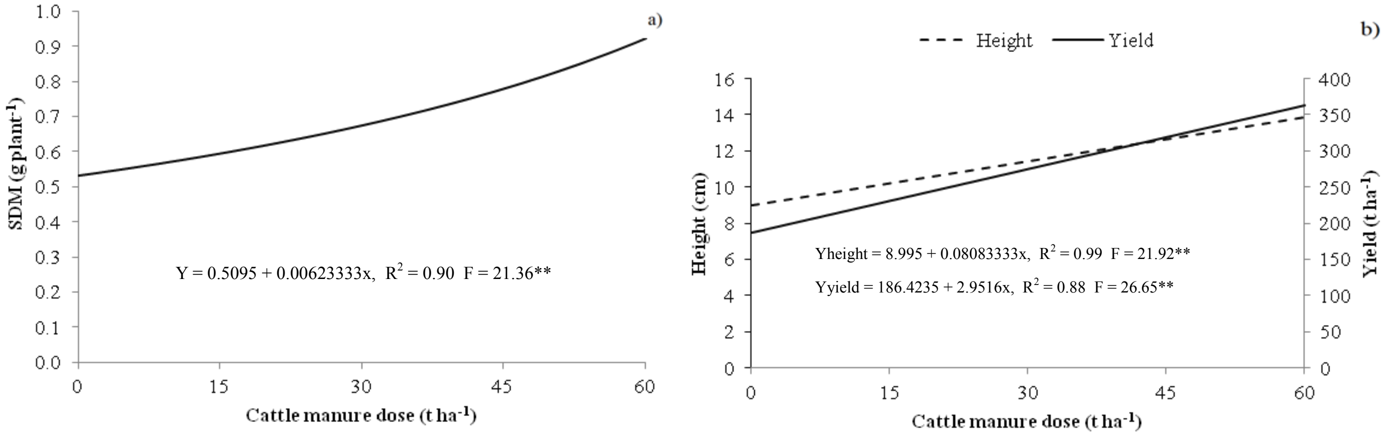

Figure 3. Shoot dry mass (a), height and yield of the arugula (b) in intercropping with lettuce as a function of cattle manure dose.

The adjustments observed for height, diameter, and shoot dry mass of lettuce and arugula in intercropping demonstrate the great contribution of the manure in the growth and yield of the plants and the possibility of continuing the response to doses even greater than those evaluated. The intercropping only received manure fertilization and, therefore, besides the natural fertility of the soil, the organic fertilizer was the only external source of nutrients. Mantovani et al. (2017) verified increases in the contents of P, K, Mg, S, and Zn in lettuce by increasing doses of cattle manure up to 160 t ha^{-1} in three soils, which were directly related to the growth of the vegetable. Although the authors did not analyze the N content in the soil, it is known that manures are generally considered N sources, and lettuce and arugula are responsive to N (BARROS JÚNIOR et al., 2011; BARROS JÚNIOR et al., 2020). In addition to increases in soil nutrient contents, there are other chemical benefits related to soil fertility, such as increases in cation exchange capacity, soil organic matter content, and pH, decreased H+Al levels, and improvements in physical and biological soil attributes (SEDIYAMA et al., 2016; MANTOVANI et al., 2017).

For intercropped lettuce, the dose of 60 t ha^{-1} provided height, diameter, and yield not significantly different (t-test, $p > 0.05$) from those obtained in single cultivation (Table 1), while for arugula, except for height, the number of leaves, shoot dry mass, and yield were lower ($p < 0.05$) than single cultivation (Table 2). The difference in response between crops can be explained by the greater response of arugula to nitrogen fertilization reported in the literature. Trani et al. (2018) recommend a 50% higher dose of N for arugula than for lettuce in topdressing fertilization. Evaluating the effect of nitrogen fertilization (0 to 195 kg ha^{-1} of N) for 'Veronica' lettuce and 'Folha Larga' arugula in intercropping, Barros Júnior et al. (2011) obtained higher yields of arugula and lettuce when these were fertilized with 195 and 127 kg ha^{-1} of N, respectively, corroborating the greater demand for N by the arugula plants.

As for the intercropping indexes, there was an effect of the cattle manure dose (Table 3), and higher values of the indexes were observed as the higher the dose applied (Figures 4, 5 and 6).

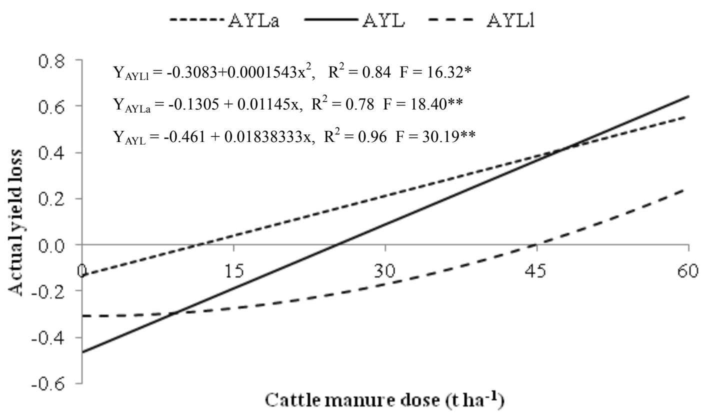

Figure 4. Actual yield loss for lettuce in intercropping with arugula (AYLa), for arugula in intercropping with lettuce (AYLl) and for intercropping (AYL) as a function of cattle manure dose.

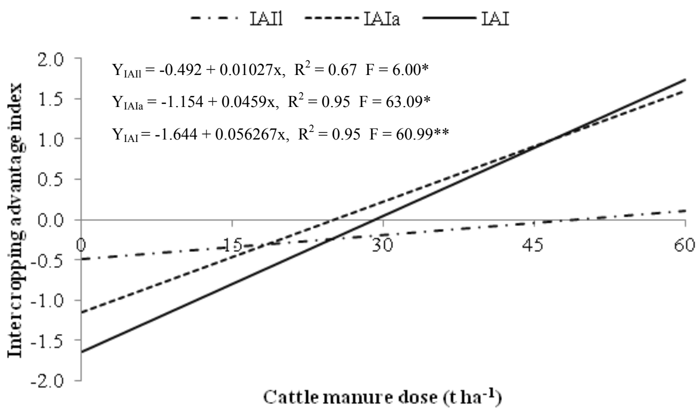

Figure 5. Intercropping advantage index for lettuce (IAIl), intercropping advantage index for arugula (IAIa) and intercropping advantage index (IAI) as a function of cattle manure dose.

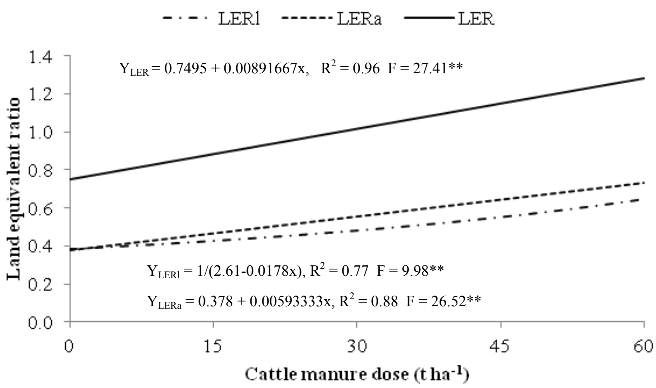

Figure 6. Land equivalent ratio index for lettuce (LERl), land equivalent ratio index for arugula (LERa) and land equivalent ratio index for the intercropping (LER) as a function of cattle manure dose.

Table 3. Summary of analysis of variance (F values and significance) and polynomial regression for land equivalent ratio index (LER), actual yield loss of intercrop (AYL) and intercropping advantage index (IAI) of crops as a function of treatments.

	AYLl	AYLa	AYL	IAIl	IAIa	IAI	LERl	LERa	LER
	Teste F								
Treatments	9.11**	5.93**	7.90**	9.25*	7.90**	8.61	9.26**	7.51**	7.16**
C.V. (%)	10.70	11.80	35.07	10.74	35.00	87.61	14.88	19.66	15.89
Regression	**	**	**	**	**	**	**	**	**

** and ^{ns} correspond to significant by F test at 1% probability and not significant ($p > 0.05$), respectively.

According to the Actual Yield Loss (AYL) and Intercropping Advantage Index (IAI) indexes, the intercropping only became advantageous after 26 and 30 t ha^{-1} of manure, respectively (Figures 4 and 5). These relatively low doses for the intercropping had a great contribution from arugula because, among the two intercropped vegetables, lettuce was the one that presented the greatest loss and only presented positive values of AYLl and IAIl when the intercropping received 46 and 50 t ha^{-1} of manure, respectively. It is worth noting that the yield loss of lettuce in the intercropping with arugula was large compared to that obtained in single cropping, explained by the interaction between the species, which was also observed by Barros Júnior et al. (2011) in the cultivation of these same species in intercrop. According to the averages presented in Table 1, even when the intercrop was fertilized with the two highest doses of cow manure, 45 and 60 t ha^{-1}, the lettuce yields were 53 and 32% lower than those obtained in single cultivation, respectively.

On the other hand, arugula showed positive AYLa and

IAIa when the intercrop was fertilized with 12 and 26 t ha^{-1} of manure, respectively. Although with these doses, arugula yields were about 50% lower than when grown single (Table 2), the AYL index considers the smaller proportion of plants present in the intercrop than in the single, corresponding to 5 and 6 rows in the bed, respectively. The proportion of plants present is one factor regulating competition between intercrops (GUERRA et al., 2022). To IAI, the higher value of arugula (R$2.50/kg) compared to lettuce (R$1.50/kg) contributed to the observed result.

Regarding the Land Equivalent Ratio (LER) index, even though the soil had good fertility, without manure fertilization, the index was 0.75; that is, it was inefficient in the use of the area because it produced 25% less than the product obtained in single cultivation, in the same unit of area. The intercropping only showed efficient land use when 29 t ha^{-1} of manure was applied. With this dose, lettuce and arugula produced 42% and 55% of their respective monocultures. The highest LER index (1.28) was obtained with the highest dose (Figure 6) since it also provided the highest values of biometry characteristics and yield of the two species.

According to Costa et al. (2017), the LER by the intercrop depends on the crops used and the production system adopted. The high response of arugula to N, as already discussed, is also observed in the LER index because when the intercrop was not fertilized with manure, the participation of arugula in the composition of the index was lower (0.38) than that of lettuce (0.43) and at the dose of 60 t ha^{-1}, which maximized the index, the participation of arugula was higher (0.73) when compared to that of lettuce (0.63) (Figure 6).

CONCLUSION

Higher growth and yield of the intercropped species were observed when the intercropping received 60 t ha^{-1} of cattle manure. However, with the linear adjustments for the characteristics, higher doses can obtain better performances.

The actual yield loss and intercropping advantage indexes showed higher values starting at doses of 26 and 30 t ha^{-1} of manure, respectively.

The highest land equivalent ratio index (1.28) was obtained with 60 t ha^{-1} of cattle manure, indicating the agronomic viability of the lettuce and arugula intercropping when fertilized only with cattle manure.

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