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Agro-economic efficiency of polycultures of arugula-carrot-lettuce fertilized with roostertree at different population density proportions

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Eruca sativa
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agronomic and economic advantages

ABSTRACT
This study aimed to evaluate the agro-economic efficiency of agrosystems of two croppings of arugula (A) and two of lettuce (L) intercropped with carrot (C) under different biomass amounts of roostertree incorporated into the soil and population density proportions between the component crops. The experimental design was a randomized block with four replications, with the treatments arranged in a 4 × 4 factorial scheme. The first factor was made up of the amounts of roostertree biomass incorporated into the soil (10, 25, 40 and 55 t ha^{-1} on a dry basis) and the second factor by the population density proportions of the component crops in the polycultures (50A-50C-50L%, 40A-50C-40L%, 30A-50C-30L% and 20A-50C-20L% of the population recommended for single crops – PRSC). The agro-economic performance of arugula, carrot and lettuce in polyculture was optimized at 25 t ha^{-1} of roostertree incorporated into the soil. The population density proportions of arugula, carrot and lettuce of 50A-50C-50L% of the PRSC provided the best agro-economic efficiency to the polyculture.

Palavras-chave:
Eruca sativa
Daucus carota
Lactuca sativa
Calotropis procera
vantagens agronômicas e econômicas

Eficiência agroeconômica de policultivos de rúcula-cenoura-alface fertilizados com flor-de-seda sob diferentes proporções de densidade populacional

RESUMO
Neste trabalho objetivou-se avaliar a eficiência agroeconômica de agrossistemas provenientes de dois cultivos de rúcula e dois de alface em consórcio com cenoura em diferentes quantidades de biomassa de flor-de-seda incorporadas ao solo e proporções de densidades populacionais entre as culturas componentes. O delineamento experimental foi de blocos casualizados com quatro repetições, com os tratamentos arranjados em esquema fatorial 4 x 4. O primeiro fator foi constituído pelas quantidades de flor-de-seda (10, 25, 40 e 55 t ha^{-1} em base seca) e o segundo pelas proporções de densidades populacionais das culturas componentes nos policultivos (50R-50C-50A%; 40R-50C-40A%; 30R-50C-30A% e 20R-50C-20A% das populações recomendadas em cultivos solteiro - PRCS). O desempenho agroeconômico do policultivo de rúcula, cenoura e alface foi otimizado na quantidade de 25 t ha^{-1} de flor-de-seda incorporada ao solo. As proporções de densidades populacionais de rúcula, cenoura e alface de 50R-50C-50A% das PRCS foram as que proporcionaram ao policultivo as melhores eficiências agroeconômicas.

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Introduction

Polyculture of tuberoses (carrot, beet and radish) with broadleaves (arugula, lettuce and coriander) is a practice that has been used in vegetable crop production systems in the semi-arid Potiguar region. The use of this practice is of great importance for having a positive effect and efficiency in relation to monocultures of vegetable crops.

The most important advantages of this crop association are the production of greater yield on a given piece of land by making use of the available growth resources more efficiently; improving soil fertility through biological nitrogen fixation with the use of legumes or green manure; increasing soil conservation through greater ground cover; reducing the incidence of pests, diseases and weed damage and improving the product quality, besides offering stability and yield uniformity (Mousavi & Eskandari, 2011).

The success of a polyculture depends on its management in relation to production factors such as fertilizer amount, population density proportion and the choice of crops involved in the system. One of the present challenges is to find agro-economic viability for arugula, carrot and lettuce intercropping systems, for an adequate amount of roostertree and optimum planting density, in order to maximize the yield and income of Potiguar family farmers that produce vegetable crops.

For greater security on the recommendation of a polyculture it is necessary to perform agro-economic analysis of intercropping because the vegetable crops have variations in price (seasonality) and the cost of production throughout the year can corroborate the success of the intercropping indicated by agro-economic efficiency indices.

Several indices or indicators have been used in both the agronomic evaluation of biological productivity and in the economic efficiency of polycultures (Bezerra Neto et al., 2012; Lima et al., 2014). The land equivalent ratio (LER) is the indicator most used by researchers of intercropping areas to assess agronomic/biological efficiency. LER provides a basis for standardization concerning single crops, so that the yields of the component crops can be added to form the combined yields (Atabo & Umaru, 2015).

Multivariate analysis of variance is one of the powerful techniques available for the evaluation of crop yields in polycultures. The philosophy of this analysis is that the yields of crops should be analyzed together, because that takes into account correlations among the yields of the component crops. In general, it is mentioned that multivariate techniques provide more adequate interpretation of the results by describing the relative superiority of treatments through the "intercropping yield" (Federer, 1993).

Evaluation of the economic efficiency of intercropping systems has been done through indicators based on the costs and benefits, called economic indicators (Bezerra Neto et al., 2010; Lima et al., 2007). Among them are gross income, net income, rate of return, profit margin (Lima et al., 2014; Oliveira et al., 2012) and productive efficiency index evaluated through data envelopment analysis (DEA) (Bezerra Neto et al., 2007a), which incorporates the biological and economic advantages of intercropping systems.

Thus, this study aimed to evaluate, through indices and indicators of agro-economic efficiency, polycultures originating from two intercropping systems of arugula and two of lettuce, intercropped with carrot fertilized with different roostertree amounts and distinct population density proportions in the semi-arid conditions of northeastern Brazil.

Material and Methods

The study was conducted at the Rafael Fernandes Experimental Farm, located at the Universidade Federal Rural do Semi-Árido - UFERSA (5° 03' 37" S and 37° 23' 50" W Gr) 20 km from the city of Mossoró, Rio Grande do Norte, from August to December 2012. According to Thornthwaite, the local climate is BShw, i.e. semi-arid (Oliveira et al., 2015). During the experimental period, the mean temperature was 27 °C, minimum 25 °C and maximum 31 °C; relative humidity was 66% and radiation 918 kJ m^{-2}.

The soil of the experimental area was classified as Oxisol dystrophic argisolic (EMBRAPA, 2006). Samples of this soil of 0-20 cm depth showed the following results: pH = 5 51; E.C. = 2.81 dS m^{-1}; O.M. = 0.81%; P = 16.5 mg dm^{-3}; K^+ = 55.35 mg dm^{-3}; Ca^{+2} = 1.91 $cmol_c$ dm^{-3}; Mg^{+2} = 1.05 $cmol_c$ dm^{-3} and Na = 2.05 $cmol_c$ dm^{-3}. For the analysis, the methodologies recommended by EMBRAPA was used (EMBRAPA, 2009).

The experimental design was a randomized block with treatments arranged in a 4 × 4 factorial scheme with four replications. The first factor was made up of the roostertree amounts incorporated into the soil (10, 25, 40 and 55 t ha^{-1} on a dry basis) and the second factor by the population densities (PDs) of the component crops in polyculture (50A-50C-50L%, 40A-50C-40L%, 30A-50C-30L% and 20A-50C-20L% of the population recommended for sole crops - PRSC). The planted arugula (A), carrot (C) and lettuce (L) cultivars were, respectively, Cultivada, Brasília and Tainá.

Intercropping was established by alternating strips of the arugula and lettuce crops between carrot strips by the proportion of area occupied: 50% for carrot, 25% arugula and 25% for lettuce (Figure 1). Each plot consisted of four strips of four rows each: a strip from a broadleaf, a strip of carrot, another strip of broadleaf and a carrot strip, flanked on one side by the first strip of a strip of carrot and on the other side

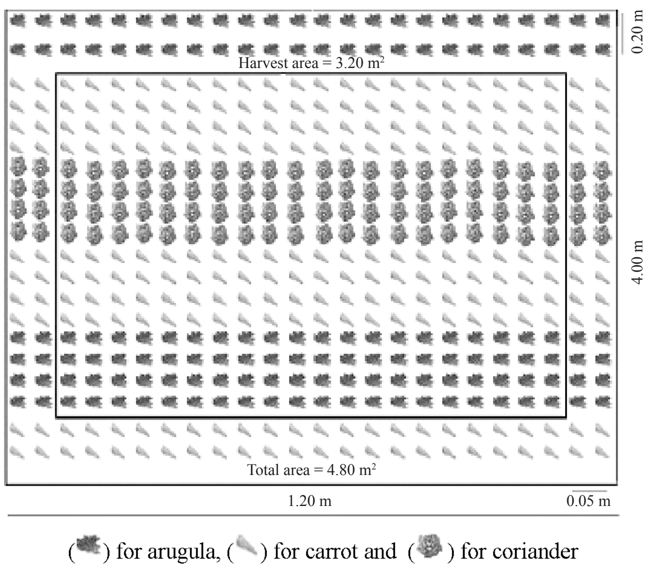

Figure 1. Graphical representation of an experimental plot of arugula-carrot-lettuce polyculture

by the last strip for an arugula strip, used as borders. The total area of the plot was 4.80 m^2, with a harvest area of 3.20 m^2.

In each block, sole plots of the arugula, carrot and lettuce crops were planted to obtain the agro-economic indicators. PDs recommended for monocrops of these vegetables are 1,000,000 plants ha^{-1} for arugula (Freitas et al., 2009), 500,000 plants ha^{-1} for carrot (Oliveira et al., 2012) and 250,000 plants ha^{-1} for lettuce (Bezerra Neto et al., 2007b).

Soil preparation consisted of mechanical cleaning with a plow followed by a harrowing and raising of the beds with a rotary hoe. Pre-planting solarization with Vulcabrilho Bril Fles 30 micron transparent plastic was performed for 30 days with the aim of combating nematodes and phytoparasites (Silva et al., 2006).

The roostertree was collected from native vegetation of the Mossoró-Apodi urban area, crushed into pieces of 2 to 3 cm, dried and stored with a moisture content of 8.3%. Samples from this green manure presented the following chemical composition: 20.56 g kg^{-1} N, 4.0 g kg^{-1} P, 35.7 g kg^{-1} K, 9.3 g kg^{-1} Ca, 7.03 g kg^{-1} Mg and a C/N ratio of 25:1.

Two incorporations of the green manure were performed on the polyculture and carrot monoculture plots. The amount of roostertree incorporated in the carrot monocrop was 42 t ha^{-1} (Silva, 2014) and in the arugula and lettuce monocrops 45 t ha^{-1} (Silva, 2012).

Sowing of the arugula and carrot crops and lettuce transplanting was done on August 1, 2012. A micro-sprinkler irrigation system was used, with two daily watering shifts, one in the morning and another in the afternoon, giving a water depth of 8 mm day^{-1} (Meurer, 2007). Control of weeds was carried out through manual weeding when necessary.

The harvest of the arugula was performed 35 days after sowing, and of the lettuce 30 days after transplanting. The second cropping of the arugula crop and of lettuce transplanting was held on November 1, 2012. The carrot harvest occurred 105 days after planting.

In addition to the green mass yield of arugula (Y_a), commercial productivity of carrot roots (Y_c) and productivity of lettuce leaves (Y_l), the following agronomic and economic indices were evaluated in the polycultures:

a) LER - land equivalent ratio of the polyculture. This represents the relative area of land under monocrop cultivation conditions necessary to achieve the same yield in intercropping. This index indicates particularly the biological efficiency of the intercropping. The LER is calculated as follows:

$$LER = \left(\frac{Y_{apc11}}{Y_{aam1}}\right) + \left(\frac{Y_{apc12}}{Y_{aam2}}\right) + \left(\frac{Y_{cpa1}}{Y_{ccm}}\right) + \left(\frac{Y_{lpca1}}{Y_{llm1}}\right) + \left(\frac{Y_{lpca2}}{Y_{llm1}}\right) \quad (1)$$

where:

Y_{apc11} - green mass yield of arugula in polyculture with carrot and lettuce in the first cropping;

Y_{aam1} - green mass yield of arugula in monocrop on the first cropping;

Y_{apc12} - green mass yield of arugula in polyculture with carrot and lettuce in the second cropping;

Y_{aam2} - green mass yield of arugula in monocrop in the second cropping;

Y_{cpa1} - commercial productivity of carrot roots in polyculture with arugula and lettuce;

Y_{cc} - commercial productivity of carrot roots in monocrop;

Y_{lpca1} - leaf productivity of lettuce in polyculture with carrot and arugula in the first cropping;

Y_{llm1} - leaf productivity of lettuce in monocrop on the first cropping;

Y_{lpca2} - leaf productivity of lettuce in polyculture with carrot and arugula in the second cropping; and,

Y_{llm2} - leaf productivity of lettuce in monocrop in the second cropping.

The LER of each plot was obtained, considering the value of the average of repetitions of monocrops over blocks in the denominator of the partial LER of each crop (LER_a, LER_c and LER_l) (Bezerra Neto et al., 2012).

b) Productive efficiency index (PEI). To calculate this index for each treatment, a DEA model with constant returns to the scale was used (Mello et al., 2013), since there was no significant difference in the scales. This model has a mathematical formulation: X_{ik} is the input i value (i = 1, ..., s) for treatment k (k = 1, ..., n); Y_{jk} is the output j value (j = 1, ..., r), for treatment k; v_i and u_j are weights assigned to inputs and outputs, respectively; and O is the treatment being analyzed.

$$\mathrm{Max}\sum_{i=1}^{r} v_i x_{io} \quad (2)$$

$$\sum_{j=1}^{s} u_j y_{jo} = 1 \quad (3)$$

$$\sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} \le 0, k = 1,\ldots,n; u_j, v_i \ge 0; i = 1,\ldots,s; j = 1,\ldots;r \quad (4)$$

The outputs were the green mass yields of arugula (sum of the first and second harvest) and the commercial productivity of carrot roots. In the modeling of this study the rate of return was used (index described in the following item) as input.

c) Multivariate analysis of variance was performed on crop yields, where each source of variation was tested by the criterion of Wilks (Λ). A discriminant function or canonical variable was estimated based on the PD proportions of the arugula, carrot and lettuce crops in polyculture using TableCurve software (Systat Software Inc, 2002).

d) Gross Income (GI) was obtained through the value of the production ha^{-1}, based on the price paid to producers in the region in December 2012. For arugula, the amount paid was R$ 1.40 kg^{-1}, for carrot R$ 0.90 kg^{-1} and for lettuce R$ 1.50 kg^{-1}.

e) Total cost (TC) of the production. The methodology described by Silva et al. (2015) was used. The TC of the production was calculated at the end of the productive process in December 2012, based on total expenditure per hectare of cultivated area, which covers the services provided by stable capital, i.e., the contribution of current capital and the value of alternative costs or opportunities.

f) Net income (NI) was obtained from the difference between GI and TC.

g) Return rate (RR) is the ratio between GI and TC and represents how many reals are obtained in return for every real invested in the evaluated intercropping system.

h) Profit margin (PM) was obtained by the ratio between NI and GI, expressed as a percentage.

Univariate analysis of variance was performed on agronomic and economic indices of polycultures as well as a multivariate analysis on the yields of the component crops in the intercropping systems using the statistical package SISVAR (Ferreira, 2011). Tukey's test at 0.05 probability was used to compare the means of the PD proportions of crops. A response curve fitting procedure was performed for each index or variable as a function of the amount of roostertree incorporated into the soil through the TableCurve package.

Results and Discussion

Agronomic/biological efficiency indices of the crops and system

No significant interactions were found between the amount of roostertree incorporated into the soil and the PDs in terms of partial land equivalent ratio for arugula ($PLER_A$), carrot ($PLER_C$) and lettuce ($PLER_L$), LER, PEI or canonical variable Z score (Figure 2A-F and Table 1). However, these variables increased with increasing amounts of roostertree added to the soil, reaching maximum values of 1.03, 0.43, 0.41, 1.86, 0.81 and 1.13 for the green manure amount of 55 t ha^{-1}.

These indices indicate that a better use of environmental resources, namely light, water, nutrients and CO_2, occurred in the intercropping system fertilized with roostertree incorporated into the soil.

The highest average values for $PLER_A$ were obtained in the 50A-50C-50L% and 40A-50C-40L% proportions, standing out from the others, while the average values for $PLER_L$, the system (LER), PEI and canonical variable Z score were achieved for the proportion 50A-50C-50L% (Table 1).

These results for the polycultures are explained by better use of environmental resources in the highest PD proportions, not observing the negative influence of competition for water and nutrients to the plants. The LERs for the assessed polycultures were greater than 1.0 (Table 1), indicating agronomic efficiency

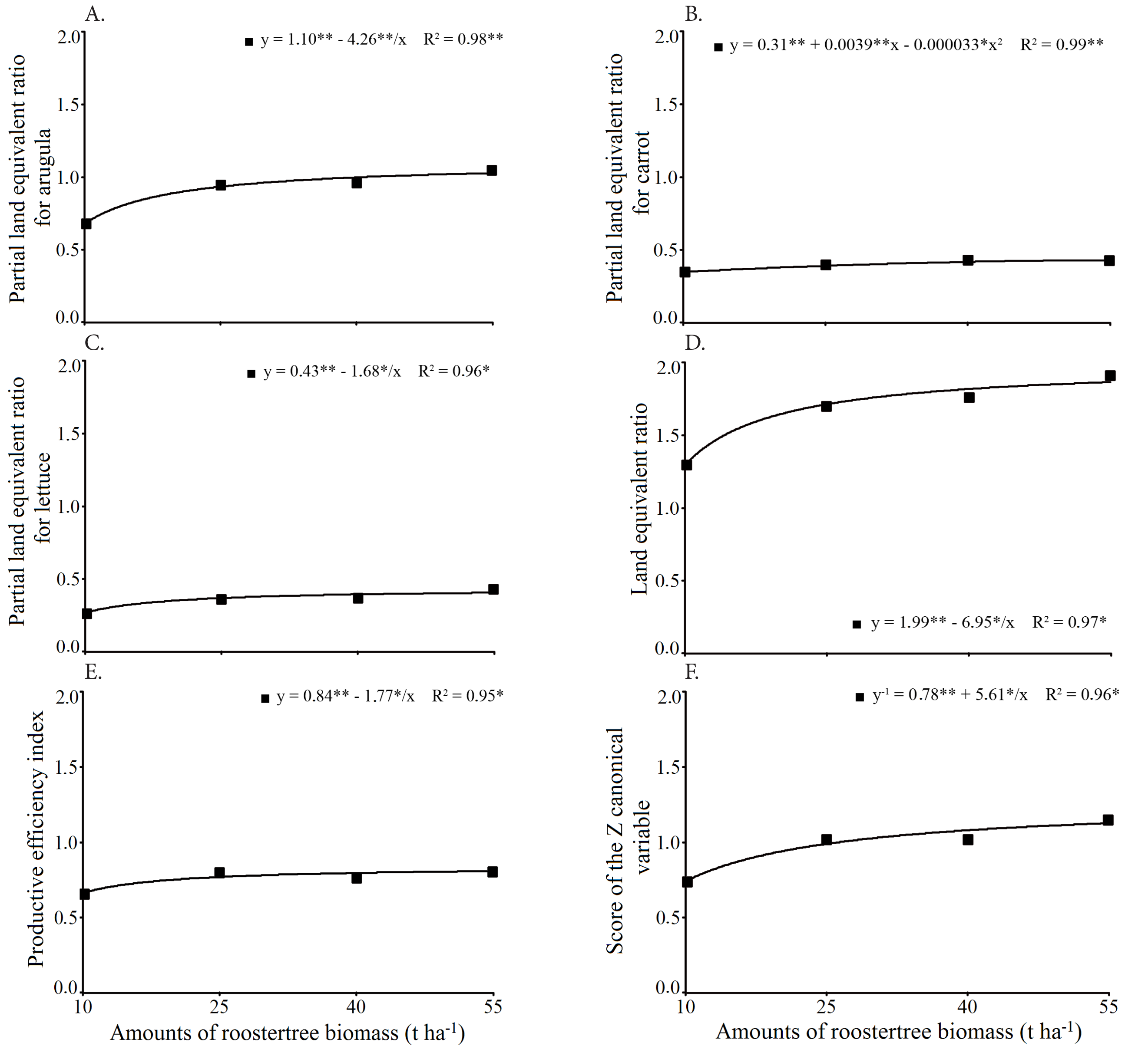

Figure 2. Partial land equivalent ratios for arugula (A), carrot (B), lettuce (C) and for the system (D), productive efficiency index (E) and canonical variable Z score (F) for different amounts of roostertree incorporated into the soil

Table 1. Partial land equivalent ratios for arugula (LER_A), carrot (LER_C), lettuce (LER_L) and for the system (LER), productive efficiency index (PEI) and canonical variable Z score for the different population density proportions of arugula and lettuce intercropped with carrot

Population density proportion (%)	LER_A	LER_C	LER_L	LER	PEI	Z score
50A-50C-50L	1.07 a	0.41 a	0.48 a	1.96 a	0.85 a	1.34 a
40A-50C-40L	0.97 a	0.40 a	0.41 b	1.77 ab	0.78 ab	1.12 b
30A-50C-30L	0.89 ab	0.39 a	0.31 c	1.62 b	0.75 bc	0.84 c
20A-50C-20L	0.71 b	0.38 a	0.24 d	1.34 c	0.70 c	0.65 d
CV (%)	24.80	16.62	14.39	15.85	11.36	15.14

* Means followed by different lowercase letters in the column differ statistically by Tukey's test at 0.05 probability

over crops grown in monocrops, by the optimal use of environmental resources for all PD proportions. This fact can be explained according to Caballero et al. (1995), who considered that when the LER is greater than 1.0, intercropping favors the growth and production of crop components. In addition, Bezerra Neto et al. (2010) reported that an intercropped system is considered efficient when the LER value is more than 1.0, since the commercial standard for the crops is reached.

The agronomic/biological indices obtained in this polyculture were much higher than those obtained by Bezerra Neto et al. (2012) in terms of LER and very similar in terms of PEI, which confirms the best use of environmental resources by vegetable crops in association.

Economic indices

There was no significant interaction between any of the factors and treatments evaluated in the economic indices (Figure 3A-D and Table 2). Increases in the GI and NI of R$ 9,413.37 and R$ 4,889.41, respectively, were observed with increasing amounts of roostertree between the lowest (10 t ha^{-1}) and highest (55 t ha^{-1}) dose, with maximum values of R$ 32,476.24 and R$ 11,674.49, respectively (Figure 3A and B). On the other hand, an increase in the RR and PM with increasing amounts of roostertree up to a maximum value of 1.65 and 37.23% at doses of 19.03 and 24.25 t ha^{-1}, respectively, was also recorded; then they decreased until the last dose was added to the soil (Figure 3C and D).

Table 2. Gross income (GI), net income (NI), rate of return (RR) and profit margin (PM) for different population density proportions of arugula and lettuce intercropped with carrot

Population density proportion (%)	GI (R$ ha^{-1})	NI (R$ ha^{-1})	RR	PM (%)
50-50-50	34,513.95 a	14,142.68 a	1.69 a	39.39 a
40-50-40	31,090.79 b	11,606.21 b	1.59 a	36.20 a
30-50-30	28,001.80 b	9,457.42 b	1.51 a	32.60 a
20-50-20	23,590.35 c	5,811.45 c	1.32 b	22.46 b
CV (%)	13.13	37.51	12.60	27.96

* Means followed by different lowercase letters in the column differ statistically by Tukey's test at 5% probability

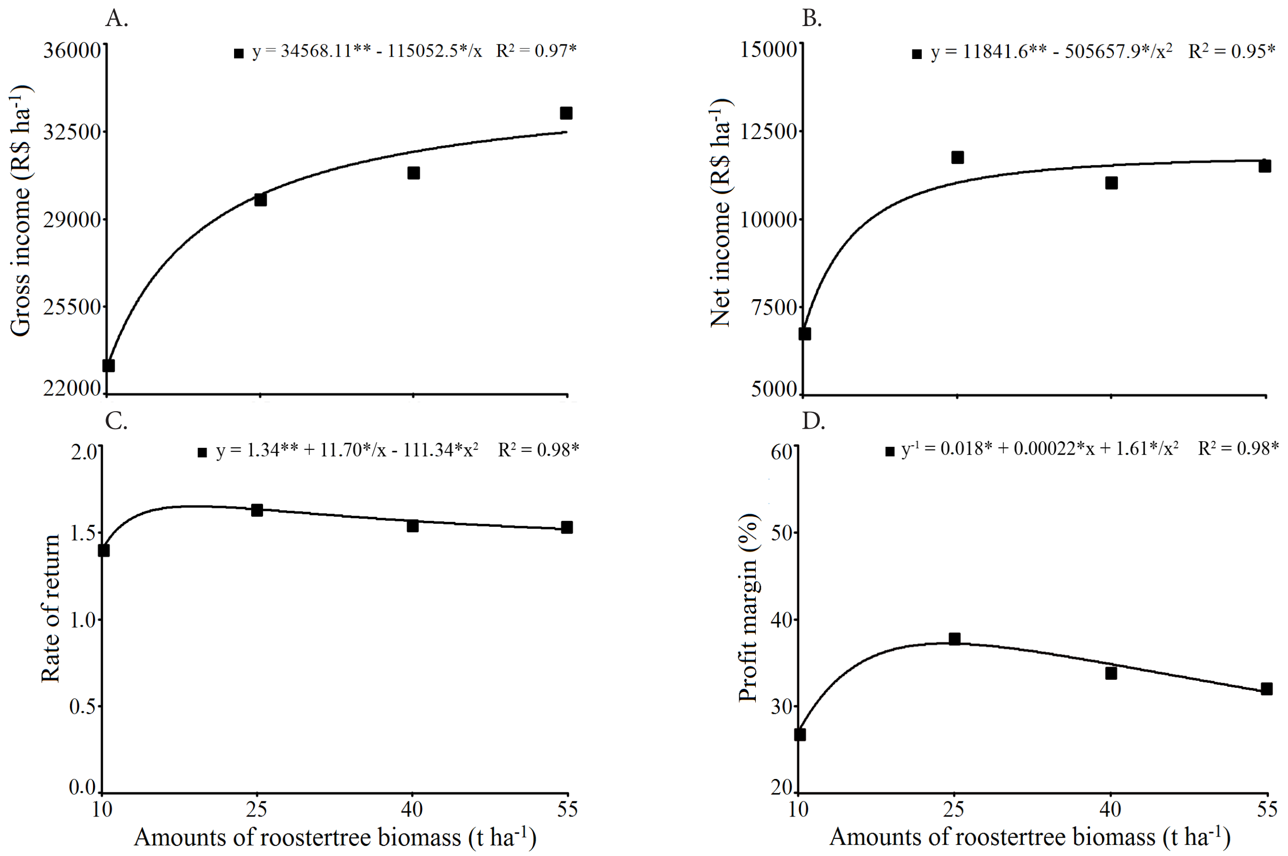

Figure 3. Gross income (A), net income (B), rate of return (C) and profit margin (D) of the polyculture of arugula, carrot and lettuce for different amounts of roostertree

The highest average values for GI, NI, RR and PM were registered for the proportion 50A-50C-50L%, although they did not differ statistically from the proportions 40A-50C-40L% and 30A-50C-30L% for RR and PM (Table 2).

The results of the economic indicators of the polycultures indicate the better agronomic/biological efficiency compared to single crops for all PD proportions. RR and PM expressed the advantage of using 19.03 and 24.25 t ha^{-1} of roostertree incorporated into the soil as a component in monetary terms, indicating that at an amount greater than this, it becomes uneconomic due to greater encumbrance of the polyculture. Possibly, these amounts of roostertree provided greater availability of nutrients to plants, influencing the efficient use of the land and crop yields in polyculture and, consequently, RR and PM. PM is one of the indices that expresses the economic value of intercropped systems better than GI, because production costs are deducted.

The economic indicators in this study were lower than the results obtained by Bezerra Neto et al. (2012), who evaluated the polyculture of arugula, carrot and lettuce in the same growing season. This difference is due to the production costs of the tested treatments; consequently, lower values for the economic assessment indicators were obtained.

Conclusions

1. The agro-economic performance of the polyculture of arugula, carrot and lettuce was optimized at 25 t ha^{-1} of roostertree incorporated into the soil.

2. The PD proportion of arugula, carrot and lettuce of 50A-50C-50L% of population recommended for sole crop provided the best agro-economic polyculture efficiency.

3. Roostertree used as green manure proved to have feasible agro-economic performance in the polyculture of arugula, carrot and lettuce.

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