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Agro-economic benefits in radish-lettuce intercropping under optimized green manuring and planting density

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ABSTRACT

One of the biggest difficulties in the intercropping of radish-lettuce is to obtain the ideal dose of green manure and the adequate planting density for the crops. Therefore, the objective of the present work was to evaluate the agro-economic benefits of radish-lettuce intercropping under the influence of green manuring with *Merremia aegyptia* (hairy woodrose) and *Calotropis procera* (roostertree) and lettuce population densities in a semi-arid environment, in two cropping seasons. The experimental design used was randomized blocks, with treatments arranged in a 4x4 factorial scheme, with 4 replicates. The first factor in this scheme consisted of equitable biomass amounts of *M. aegyptia* and *C. procera* at doses of 20, 35, 50 and 65 t/ha on a dry basis, and the second factor of lettuce population densities of 150, 200, 250 and 300 thousand plants/ha. The production of radish and lettuce and its components, in addition to the agro-economic indicators, system productivity index (SPI), land equivalent coefficient (LEC) and monetary equivalent ratio (MER) were evaluated. The greatest agro-economic benefits of the intercropped radish-lettuce were obtained with SPI of 15.37 t/ha, LEC of 1.27 and MER of 1.30, respectively, in the combination of 65 t/ha of *M. aegyptia* and *C. procera* biomass with the lettuce population density of 300 thousand plants/ha. The maximum commercial productivity of radish roots in the intercropping system was 8.45 t/ha in the combination of the biomass amount of 20 t/ha of *M. aegyptia* and *C. procera* and lettuce population density of 300 thousand plants/ha, while the maximum lettuce leaf productivity optimized in intercropping was 17.72 t/ha, in the combination of green manures biomass amount of 65 t/ha and population density of 300 thousand plants/ha of lettuce. The use of spontaneous species from the Caatinga biome as green manure in the radish-lettuce intercropping provides optimized agro-economic benefits in a semi-arid environment.

Keywords: *Lactuca sativa*, *Raphanus sativus*, *Merremia aegyptia*, *Calotropis procera*, productive and economic optimization.

RESUMO

Benefícios agroeconômicos no consórcio de rabanete e alface sob adubação verde e densidade de plantio otimizadas

Uma das maiores dificuldades do consórcio de rabanete-alface é obter a dose ideal de adubo verde e a densidade de plantio adequada das culturas. Diante disso, o objetivo do presente trabalho foi avaliar os benefícios agroeconômicos em consórcios de rabanete-alface sob influência da adubação verde com *Merremia aegyptia* e *Calotropis procera* e densidades populacionais de alface em ambiente semiárido, em dois anos de cultivo. O delineamento experimental utilizado foi em blocos ao acaso, com os tratamentos dispostos em esquema fatorial 4x4, com 4 repetições. O primeiro fator deste esquema consistiu de quantidades equitativas de biomassa de *M. aegyptia* e *C. procera* nas doses de 20, 35, 50 e 65 t/ha em base seca, e o segundo fator de densidades populacionais de alface de 150, 200, 250 e 300 mil plantas/ha. A produção do rabanete e da alface e seus componentes, além dos indicadores agroeconômicos, índice de produtividade do sistema (SPI), coeficiente equivalente de terra (LEC) e razão equivalente monetária (MER) foram avaliados. Os maiores benefícios agroeconômicos do consórcio de rabanete-alface foram obtidos com SPI de 15,37 t/ha, LEC de 1,27 e MER de 1,30, respectivamente na combinação de 65 t/ha de biomassa de *M. aegyptia* e *C. procera* com densidade populacional de alface de 300 mil plantas/ha. A produtividade comercial máxima otimizada de raízes de rabanete no consórcio foi de 8,45 t/ha na combinação da quantidade de biomassa de 20 t/ha de *M. aegyptia* e *C. procera* e densidade populacional de alface de 300 mil plantas/ha, enquanto a produtividade máxima de folhas de alface otimizada em consórcio foi de 17,72 t/ha, na combinação de quantidade de biomassa dos adubos verdes de 65 t/ha e densidade populacional de 300 mil plantas/ha de alface. A utilização de espécies espontâneas do bioma Caatinga como adubo verde no consórcio de rabanete-alface proporciona benefícios agroeconômicos otimizados em ambiente semiárido.

Palavras-chave: *Lactuca sativa*, *Raphanus sativus*, *Merremia aegyptia*, *Calotropis procera*, otimização econômica e produtiva.

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Vegetable production systems in family farming have their production focused on the family's consumption and the sale of their surplus to cover their essential expenses. These production systems are characterized by intensive cultivation of crops, increasingly demanding the improvement of techniques or practices to obtain high productivity and better quality and quantity of products (Alves *et al.*, 2012). One of these practices is the intercropping of crops, which consists of cultivating two or more crops in close proximity, with the objective of producing a greater yield per area, making use of environmental resources that otherwise would not be used by a single crop. Generally, the total productions per hectare of the intercropped crops are higher than in the single crop, even when the production of each component individually is reduced.

One of the challenges in the success of this practice has been how to properly manage the production factors in the cultivation of the vegetables, especially between tuberous and leafy vegetables. Among these production factors are the types of crops, the planting population density of these crops and the types of fertilizers and their quantities. One of the principles of intercropping is to use companion and complementary plants in the crops, as they provide greater productivity per planted area; biological diversification of the environment; keep nutrients in plant foods in balance; increase soil moisture due to greater land cover and shading; it reduces water losses through plant transpiration and reduces soil erosion (Meira *et al.*, 2012). Radish and lettuce satisfy this principle as they are considered companion crops.

On the other hand, among the types of organic fertilizers, those of vegetable origin that stood out in the production of leafy and tuberous vegetables in Northeastern Brazil, are green manures, hairy woodrose and roostertree from spontaneous plants in the Caatinga biome (Silva *et al.*, 2013). Among its effects on soil fertility are increased organic matter content, greater nutrient availability and effective cation exchange capacity, decreased aluminum content and nutrient mobilization (Silva

et al., 2016).

Research carried out in the Brazilian semiarid region with the spontaneous species hairy woodrose (*Merremia aegyptia*) and roostertree (*Calotropis procera*) as green manures in single crops of lettuce (Góes *et al.*, 2011) and radish (Linhares *et al.*, 2011) have shown good results.

Another production factor that interacts in the intercropping system is the population density of crops. Due to better use of environmental resources and the interaction between the component crops of intercropped systems, it will lead to a maximization of the growth factors, thus obtaining advantages reflected in increased productivity, production, soil protection, weed control, efficient use of labor, obtaining two simultaneous productions and improving income distribution (Lima *et al.*, 2013).

Planting density is one important production factor that influences plant development. This factor promotes competition between individuals of same or different species for growth resources such as water, light and nutrients, and can affect production and its components. The influence of plant density on the quality of intercropped vegetables is reported by Bezerra Neto *et al.* (2005) who, evaluating the agronomic performance of the intercrop of carrot and lettuce under population densities, verified that the increase in the association of densities favored the total and commercial productivity of carrot roots, in addition to increasing the percentage of short class roots.

In this context, this study aimed to evaluate the agro-economic benefits of radish-lettuce intercropping under the influence of green manuring with hairy woodrose and roostertree and of lettuce population densities in a semi-arid environment, in two cropping seasons.

MATERIAL AND METHODS

The work was developed over two cropping seasons, from October 2020 to January 2021 and July to October 2021, in the experimental farm 'Rafael Fernandes' belonging to the Federal Rural University of the

Semi-Árido (UFERSA), in the city of Mossoró-RN (5°03'37"S, 37°23'50"W and 80 m altitude). The climate of the region, according to the Köppen-Geiger classification, is BShw, that is, dry and very hot, with two distinct seasons that include the dry season, from June to January and the rainy season, from February to May. During the experimental periods, the average values recorded for minimum, average and maximum temperatures, relative humidity, precipitation, solar radiation and wind speed for the 2020 and 2021 crop years were respectively: 21.3; 28.6 and 35.9°C; 22.8; 29.7 and 36.6°C; 69.3 and 66.7%; and 8.20 and 0.60 mm; 20.5 and 22.9 MJ/m²/day and 1.62 and 2.41 m/s (INMET, 2021).

The soils of the experimental areas were classified as a typical Red Yellow Dystrophic Argisol with a sandy-loam texture (Santos *et al.*, 2018). In each experimental area, simple soil samples were collected from the 0-20 cm surface layer, homogenized to obtain a composite sample representative of the area, whose results in cultivation in 2020 were: pH (water) = 6.3; EC = 0.44 dS/m; O.M. = 11.90 g/kg; N = 0.60 g/kg; P = 24.00 mg/dm³; K = 52.28 mg/dm³; Ca = 2.50 cmol_c/dm³; Mg = 0.80 cmol_c/dm³; Na = 1.73 mg/dm³; Cu = 0.50 mg/dm³; Fe = 5.70 mg/dm³; Mn = 11.20 mg/dm³; Zn = 3.80 mg/dm³. In the 2021 cultivation year, were: pH (water) = 6.6; EC = 0.56 dS/m; O.M. = 12.97 g/kg; N = 0.65 g/kg; P = 32.00 mg/dm³; K = 61.27 mg/dm³; Ca = 2.37 cmol_c/dm³; Mg = 0.65 cmol_c/dm³; Na = 2.30 mg/dm³; Cu = 0.30 mg/dm³; Fe = 4.80 mg/dm³; Mn = 6.10 mg/dm³; Zn = 2.70 mg/dm³.

The experimental design used was a randomized complete block in a 4x4 factorial scheme, with four replicates. The first factor consisted of equitable biomass amounts of the green manures hairy woodrose and roostertree of 20, 35, 50 and 65 t/ha on a dry basis and the second factor of population densities of the lettuce crop of 150, 200, 250 and 300 thousand plants/ha, corresponding to 60, 80, 100 and 120% of the recommended density in single crop (RDSC). The recommended lettuce density for single crop in the region is 250 thousand pls/ha and radish of 500 thousand pls/

ha. In each block, plots of radish and lettuce were planted in single crops and fertilized with equitable biomass amounts of green manures optimized by research in the region to obtain the agronomic and economic indexes of the intercropping systems.

The intercropping of vegetables was established in alternating strips of four rows in the proportion of 50% of the area for radish and 50% of the area for lettuce. Each intercropping plot consisted of four rows of radish alternating with four rows of lettuce, flanked by two rows of each crop on each side used as border. The total area of the plot was 2.88 m² (2.40 x 1.20 m), with harvest area of 1.60 m² (1.60 x 1.00 m), this area consisting of two central rows of plants of each crop, excluding the last two plants of each row also used as border. The spacing of the radish in the intercropping treatments was 0.20 x 0.05 m providing a population of 500 thousand plants/ha. The spacings of lettuce in the treatments were 0.20 x 0.15 m, 0.20 x 0.12 m, 0.20 x 0.10 m and 0.20 x 0.08 m providing a population of 150, 200, 250 and 300 thousand plants of lettuce per hectare.

The single crops of the vegetables were established in a total area of 1.44 m² (1.20 x 1.20 m), with harvest area of 0.80 m² (0.80 x 1.00 m). The single crop plots of each crop consisted of 6 rows, with the radish planted at 0.20 x 0.10 m spacing (Silva *et al.*, 2017) and lettuce planted at 0.20 x 0.20 m spacing (Góes *et al.*, 2011), thus providing populations of 500 and 250 thousand plants per hectare, respectively. These vegetables were harvested in the 4 central rows of cultivation, excluding the lateral rows, as well as the first and last plants of each row of cultivation in the useful area, considered borders.

Before installation of the experiments, the soils were prepared, starting with the mechanical cleaning of the areas with the aid of a tractor with an attached plow, followed by a plowing and harrowing and mechanized lifting of the beds with a rotary hoe. Subsequently, a pre-planting solarization was carried out with a transparent plastic of the Vulca Brilho Bril Flex type (30 microns) for 30

days in order to combat phytopathogenic microorganisms present in the soil that could affect crop productivity (Silva *et al.*, 2006).

After the solarization period, the material used as green manure was incorporated on December 9th in 2020 and on September 13th in 2021 using hoes. From incorporation to harvest, daily micro sprinkler irrigations were carried out divided into two shifts (morning and afternoon). The amount of supplied water 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 depth, when necessary, of approximately 8 mm/day.

The materials used as green manures were the hairy woodrose (*Merremia aegyptia*) and roostertree (*Calotropis procera*), cut before the beginning of flowering, collected from native vegetation in various rural areas of the municipality of Mossoró, RN. After collections, the plants were crushed into fragments of two to three centimeters, which were dehydrated at room temperature until reaching 10% moisture content and later subjected to laboratory analysis, whose chemical compositions were obtained in 2020: N = 16.60 g/kg; P = 2.79 g/kg; K = 37.80 g/kg; Mg = 7.07 g/kg and Ca = 19.35 g/kg, for hairy woodrose; N = 21.90 g/kg; P = 1.92 g/kg; K = 20.90 g/kg; Mg = 9.20 g/kg and Ca = 17.00 g/kg for roostertree. In 2021: N = 15.30 g/kg; P = 4.00 g/kg; K = 25.70 g/kg; Mg = 7.03 g/kg and Ca = 9.30 g/kg, for hairy woodrose; N = 18.40 g/kg; P = 3.10 g/kg; K = 24.50 g/kg; Mg = 13.50 g/kg and Ca = 16.30 g/kg for roostertree.

The radish cultivar 'Crimson Gigante' was sown on December 29, 2020 in the first crop and on September 28, 2021 in the second crop in holes approximately 3 cm deep with 2 to 3 seeds per hole and covered with a layer of organic substrate. The radish was thinned seven days after sowing, leaving one plant per hole. The lettuce cultivar 'Tainá' was sown in 200-cell polystyrene trays, three seeds per cell, on December 8, 2020 in the first crop

and on September 7, 2021 in the second crop for seedling production in the company HortVida Agrícola LTDA-ME. The lettuce was thinned after seven days, leaving one seedling per cell. Seedlings of this leafy crop were transplanted to the field, in 5.0 cm deep pits in the beds, 21 days after sowing (DAS) on December 29, 2020 in the first crop and on September 28, 2021 in the second cultivation.

Weeds were controlled manually whenever necessary. No chemical pest and disease control methods were used. The radish was harvested 30 days after sowing, while lettuce was harvested 28 days after transplanting, both in the first and in the second cultivation.

For the lettuce crop we evaluated plant height and diameter, number of leaves per plant, leaf productivity and dry mass of shoots. For radish crop we evaluated plant height, longitudinal diameter of roots, shoot and root dry mass, total and commercial productivity of roots. The agro-economic efficiency indexes used in the evaluation of the intercropped systems of radish and lettuce were the system productivity index (SPI), the land equivalent coefficient (LEC) and the monetary equivalent ratio (MER).

The system productivity index (SPI) was calculated by the following expression (Chaves *et al.*, 2020): $SPI = [(Y_r/Y_l) \times Y_{rl}] + Y_{rl}$, where Y_r is the commercial productivity of radish roots; Y_l the productivity of lettuce leaves in monoculture; Y_{rl} the productivity of lettuce leaves intercropped with radish and Y_{rl} the commercial productivity of radish roots intercropped with lettuce. The main advantage of SPI, expressed in t/ha, is that it standardizes the productivity of the secondary crop (lettuce) in relation to the main crop (radish).

The land equivalent coefficient (LER) was calculated using the following expression (Pinto *et al.*, 2012): $LEC = LER_r \times LER_l$, where LER_r and LER_l represent the partial land equivalent ratios of radish and lettuce. For the intercropping between two crops, the minimum expected yield

coefficient is 25%, that is, the yield advantage becomes viable if the LEC value exceeds 0.25.

The monetary equivalent ratio (MER) was determined by the following expression (Afe & Atanda, 2015): $MER = (GI_n + GI_r)/GI_r$, where GI_n is the gross income of radish intercropped with lettuce; GI_l is the gross income of lettuce intercropped with radish and GI_r is the highest gross income of radish in monoculture, when compared to that of lettuce. This index measures the economic superiority or not, of the intercropping over the most economical monoculture.

Univariate analysis of variance for a randomized block design in a factorial scheme was used to assess the homogeneity of variances between croppings in each analyzed variable. Given the homogeneity of these variances, an average of the tested treatments was calculated. Then, a regression analysis was performed for each variable, where a response surface adjustment procedure was performed as a function of the equitable amounts of biomass of the green manures incorporated into the soil and of the lettuce population densities, through the Table Curve 3D software. The F test was used to verify whether or not there was a significant difference between the intercropped and monocropped systems.

RESULTS AND DISCUSSION

Performance of the lettuce crop

The results of the analyses of variance and regression of the agronomic characteristics evaluated in lettuce are presented in Table 1. Significant interaction between production factors, equitable biomass amounts of the green manures and population densities of lettuce was recorded in the plant height, in the transversal diameter of the leaves, in the number of leaves per plant and in the dry mass of lettuce shoots. However, there was no significant interaction between these production factors in lettuce leaf productivity.

A response surface was adjusted for all lettuce characteristics as a function of the tested treatment-factors. The maximum values obtained were 17.51 and 18.90 cm for plant height and leaf transversal diameter (Figures 1A and 1B), 15.7 leaves per plant (Figure 1C) and 17.72 and 0.123 t/ha for leaf productivity and dry mass of shoots (Figures 1D and 1E) in the combinations of equitable amounts of the green manures biomass and lettuce population densities of 65 and 300; 20 and 300; 20 and 300; 65 and 300 and 20 t/ha and 300 thousand plants per hectare, respectively (Figures 1A to 1E).

The definition of fertilizer doses and the number of plants per area is of fundamental importance to obtain

gains in the production of intercropping systems when different species are planted together. It is known that higher doses of fertilizers allow better plant development and growth, and when associated with high population densities of one of the crops, the system productivity and crop growth expressed by plant height can be optimized, due to better utilization by the intercropping system of nutrients made available by fertilization and the environmental resources involved, thus optimizing these system production variables.

This phenomenon can be observed in the results obtained with the plant height and lettuce leaf productivity, where the greatest amount of the green manures interacting with a high lettuce population density provided the highest results for these variables. This means that in the intercropped system, lettuce made better use of the availability of nutrients and environmental resources at a population density of 120% RDSC, minimizing interspecific and, mainly, intraspecific competition in the lettuce crop. These results corroborate observations made by Filgueira (2013), when reporting that the efficiency of the use of organic fertilizer is related to increased sprouting and production of green mass of plants due to the increase in nutrient availability and, thus, favoring physical properties and activities of soil organisms. This same author states that

Table 1. F and mean values for plant height (PH), number of leaves per plant (NLP), transversal diameter (TD), productivity of leaves (PL) and dry mass of shoots (DMS) of lettuce intercropped with radish as a function of equitable biomass amounts of *M. aegyptia* and *C. procerca* and lettuce population densities. Mossoró, UFERSA, 2020-2021.

Sources of variation	DF	PH	NLP	TD	PL	DMS
Blocks	3	2.29 ^{ns}	4.09*	3.08*	0.53 ^{ns}	0.67 ^{ns}
Amounts of <i>M. aegyptia</i> and <i>C. procerca</i> biomass (A)	3	8.28**	17.41**	21.52**	40.36**	10.02**†
Population densities of lettuce (D)	3	171.00**	33.66**	97.31**	182.39**	14.59**
A x D	9	4.37**	3.40*	1.85 ^{ns}	1.96 ^{ns}	3.19*
Monocropping (M) x Intercropping (I)	1	5.33*	0.10 ^{ns}	8.78**	83.06**	0.02 ^{ns}
Regression	2	79.95**	26.24**	74.20**	104.11**	13.43**
Error	13	0.2965	0.4807	0.1367	0.8728	0.000034
Cropping systems						
Intercropping		15.26b	13.36a	17.14b	11.70b	0.11a
Monocropping		15.97a	13.35a	17.88a	16.69a	0.11a
CV (%)		3.89	6.39	3.34	9.11	8.47

† ** = P<0.01; * = 0.05; ns = P>0.05. *Means followed by different lowercase letters in the column differ statistically from each other by the F test at 5% probability level.

in leafy crops, the supply of adequate amounts of nitrogen favors vegetative development, expanding the active photosynthetic area and thus increasing the productive potential. Thus, the combination of the two species (hairy woodrose and roostertree) that have nitrogen in satisfactory amounts, meets the needs of crops such as the lettuce in intercropped system with high plant density.

Batista *et al.* (2016), studying the efficiency of the intercropping of arugula and carrot in different populations, state that the increase in the production of green mass of the arugula with the increase in the population density of the leafy vegetable is due to the greater number of plants per area.

On the other hand, the transversal diameter of leaves, the number of leaves per plant and dry mass of lettuce shoots are characteristics that depend mainly on the population density of the crop, as this production factor dictates the level of competition between the intercropped crops.

Comparing the intercropping system with monocrop, we observed that monocrop was superior to intercropping in terms of plant height, leaf productivity and dry mass of lettuce shoots (Table 1). These results are due to the lower intraspecific competition of lettuce in monocrop. It is known that the proximity of the crops in the intercropping predisposes to interspecific competition, that is, greater competition for light, water and nutrients, in addition to oxygen, carbon dioxide and space (Nascimento *et al.*, 2018). This behavior explains the better performance of lettuce in monocrop compared to intercropping in this study.

Performance of the radish crop

The results of the variance and regression analyzes of the agronomic characteristics evaluated in radish are shown in Table 2. No significant interaction between production factors, equitable biomass amounts of the green manures and population densities of lettuce was recorded in the plant height, dry mass of shoots, dry mass of roots, longitudinal diameter of roots, and in the productivity of commercial and total

radish roots.

A response surface was adjusted for all these radish characteristics as a function of the tested treatment-factors.

The maximum values obtained were 25.32 cm and 38.59 mm for plant height and longitudinal diameter of roots (Figures 2A and 2B), 0.147 and 0.140

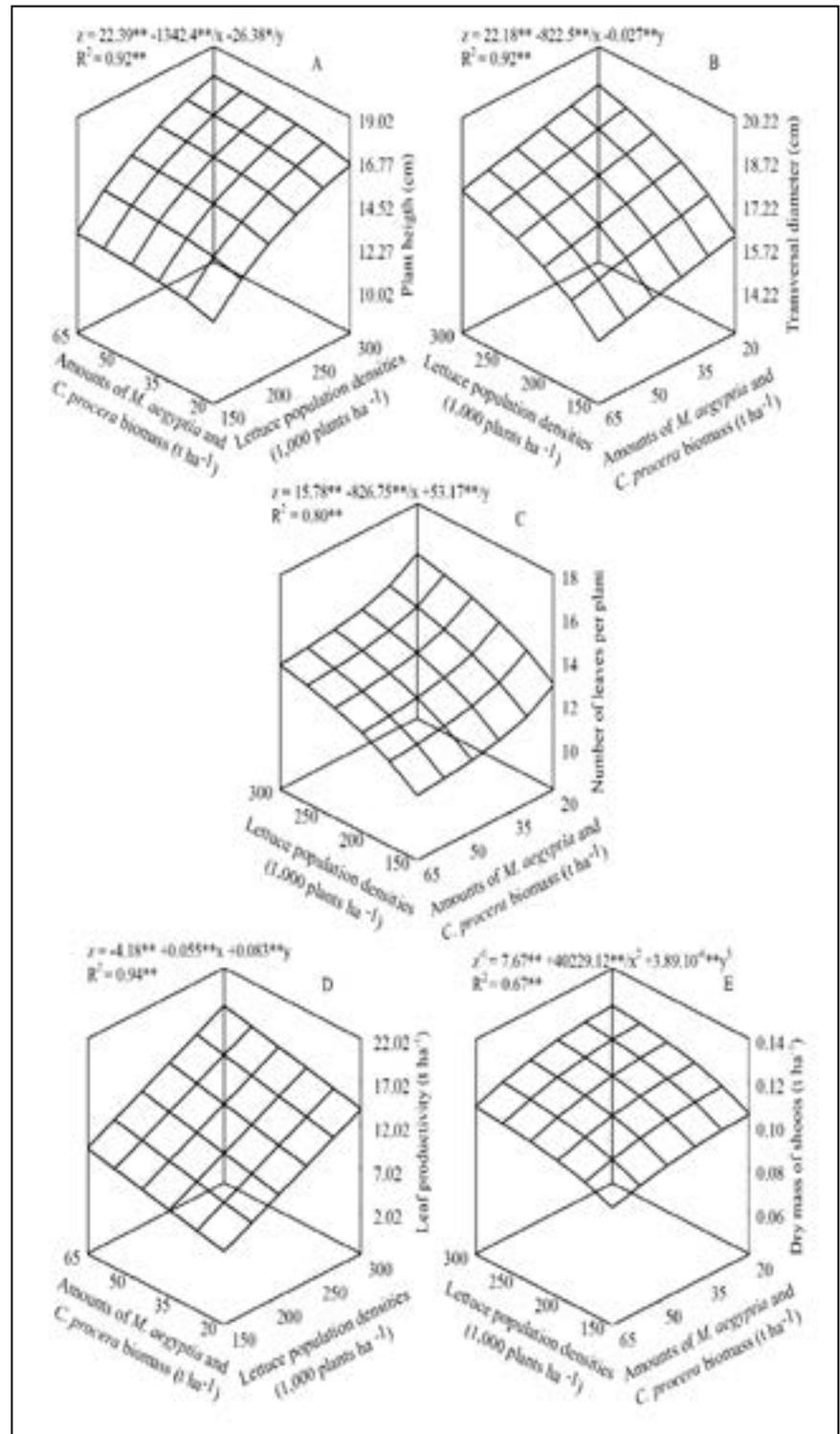


Figure 1. Plant height and transversal diameter of lettuce leaves (A and B), number of leaves per plant (C) and leaf productivity and dry mass of shoots (D and E) of lettuce intercropped with radish at different equitable biomass amounts of *M. aegyptia* and *C. procerus* incorporated into the soil and at diverse lettuce population densities. Mossoró, UFERSA, 2020-2021.

t/ha for dry mass of shoots and of roots (Figures 2C and 2D) and 8.45 and 10.28 t/ha for the productivity of commercial and total radish roots (Figures 2E and 2F) in the combinations of equitable amounts of the green manures biomass and lettuce population densities of 65 and 300 and 65 and 252; 41 and 300 and 41 and 300; and 20 and 300 and 20 t/ha and 300 thousand plants per hectare, respectively (Figures 2A to 2F).

The results of the height of radish plants may be associated with the intense competition for light, provided by the high population density of lettuce, which promoted the growth of radish plants. With less space between crops, plants grew in search of light, the main climatic element that determines their growth, in addition to water and nutrients available in the soil solution, according to Taiz & Zeiger (2013).

For the dry mass of shoots and of roots, it can be inferred that the greater competition imposed by the high number of lettuce plants in the area negatively impacted the photosynthesis of radish plants and, consequently, allowed the shoot dry mass and radish roots peaked in a raised lettuce population along with intermediate equitable amounts of the green manure's biomass. Paciullo *et al.* (2011), state that shading between plants reduces the production of dry mass, as it causes a deficiency in the translocation of photoassimilates; therefore, maximum dry mass production was achieved at the highest lettuce densities. In intercropped systems, where soil nutritional conditions are adequate for cultivation, competition for light can be more intense, and the use of high densities can increase competition for this natural resource (Nascimento *et al.*, 2018).

For commercial and total productivity of radish roots, the increase in the lettuce population density provided maximum yields in the smallest equitable amount of the green manures and in the high density of lettuce. These responses are due to the high density of lettuce plants, which provided changes in the architecture of radish in the intercropping, in its growth,

development, absorption and partition of assimilated by the plants in the least amount of fertilizers (Adams *et al.*, 2019). The interaction between plants in a community induces morphological and physiological changes, which are important to determine the productive potential of crops. It is known that the plant population in intercropped systems depends on the type and growth habit of the crops, soil fertility, water and other growth requirements (Balasubramaniyan & Palaniappan, 2001). In the case under study, the architecture and morphology of radish

and lettuce crops are completely different with regard to the demand for environmental resources, as they demand at different times and occupied spaces.

Comparing the intercropping system of radish with lettuce with its monocrop, it can be observed that no significant difference was registered between the mean values of dry mass and longitudinal diameter of roots, as well as in the commercial and total productivities of radish roots (Table 2). On the other hand, a significant difference was observed between the

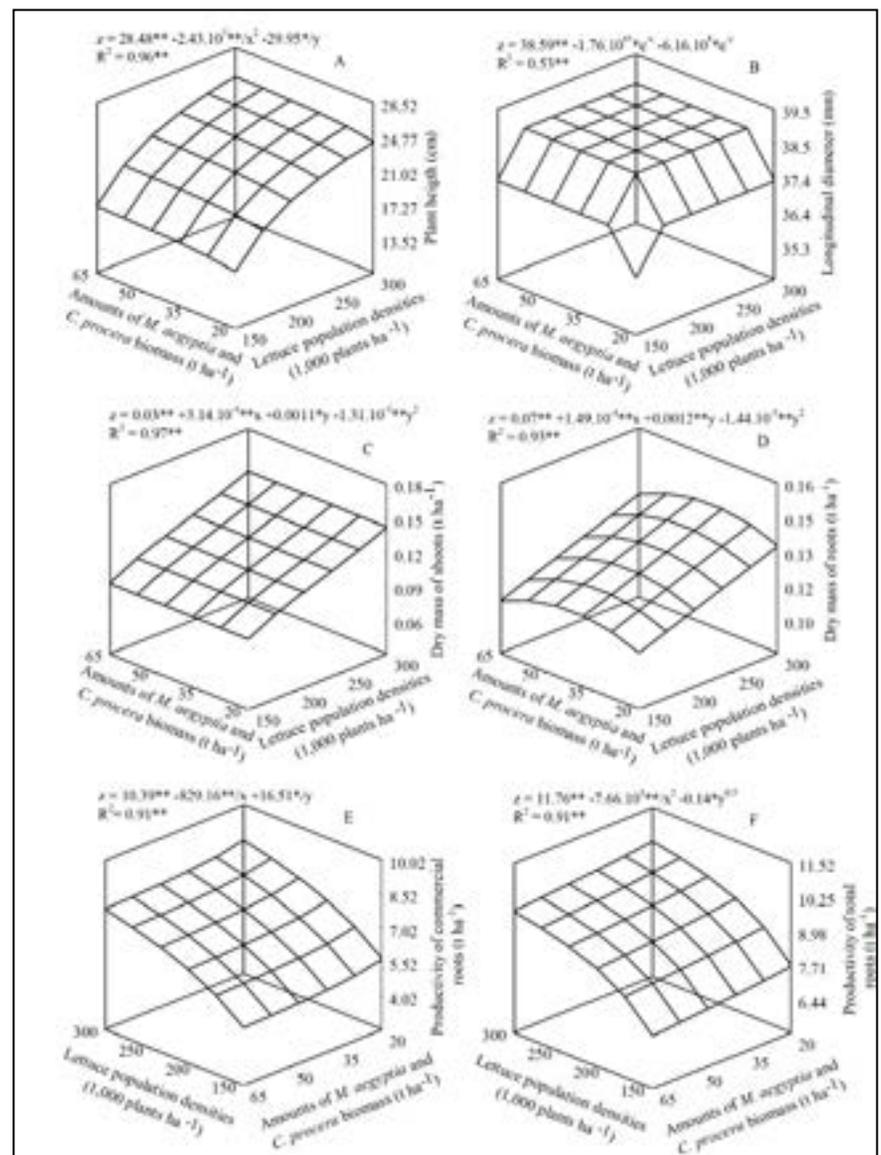


Figure 2. Plant height (A), longitudinal diameter (B), dry mass of shoots (C) and of roots (D), productivity of commercial (E) and total roots (F) of radish intercropped with lettuce at different equitable biomass amounts of *M. aegyptia* and *C. procerus* incorporated into the soil and at diverse lettuce population densities. Mossoró, UFERSA, 2020-2021.

mean values of these systems in the plant height and in the dry mass of radish shoots, with the intercropped system surpassing the monocrop. Such behavior may be related to the close C/N ratio existing between the species of the green manures used, thus ensuring a decomposition and rapid mineralization of nutrients, especially nitrogen (Giacomini *et al.*, 2003), in a short period of time between the manuring and the period of maximum nutritional demand of the radish (Silva *et al.*, 2017). This crop has characteristics such as plant height and dry mass of shoots increased with high doses of nitrogen fertilization (El-Desuki *et al.*, 2005).

Agro-economic indicators of the intercropped system

Significant interactions between the studied production factors, equitable biomass amounts of the green manures and lettuce population densities were not recorded for the agro-economic indexes SPI, land equivalent coefficient LEC and monetary equivalent ratio MER (Table 3).

However, a response surface was fitted for each agro-economic index (Figure 3). The maximum values reached for SPI, LEC and MER were 15.37 t/ha,

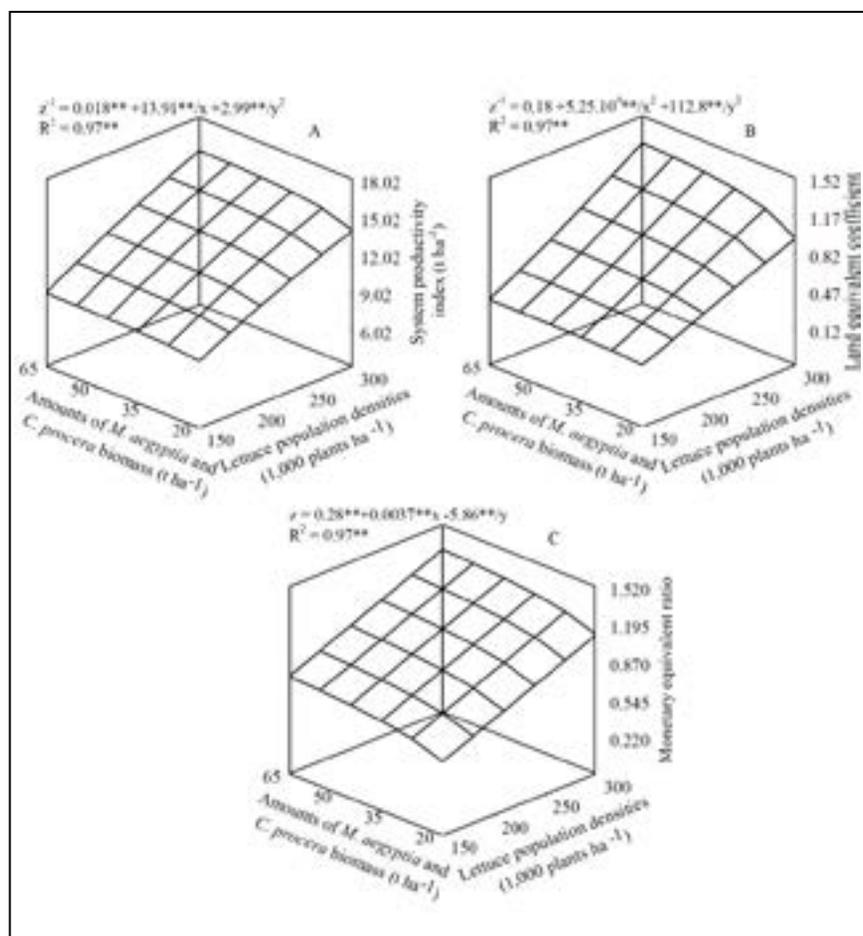


Figure 3. System productivity index (A), land equivalent coefficient (B), and monetary equivalent ratio (C) of radish intercropped with lettuce at different equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and at diverse lettuce population densities. Mossoró, UFRSA, 2020-2021.

Table 2. F and mean values for plant height (PH), dry mass of shoots (DMS) and roots (DMR), longitudinal diameter (LD), productivity of commercial (PCR) and total roots (PTR) of radish intercropped with lettuce as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* and lettuce population densities. Mossoró, UFRSA, 2020-2021.

Sources of variation	DF	PH	DMS	DMR	LD	PCR	PTR
Blocks	3	0.13 ^{ns}	2.94*	1.18 ^{ns}	1.55 ^{ns}	0.64 ^{ns}	0.12 ^{ns}
Amounts of <i>M. aegyptia</i> and <i>C. procera</i> biomass (A)	3	0.95 ^{ns}	0.45 ^{ns}	3.24*	7.54**	4.89**	2.77 ^{ns}
Population densities of lettuce (D)	3	55.18**	45.81**	14.44**	9.39**	43.37**	36.88**†
A x D	9	0.52 ^{ns}	0.37 ^{ns}	0.15 ^{ns}	1.09 ^{ns}	0.22 ^{ns}	0.76 ^{ns}
Monocropping (M) x Intercropping (I)	1	6.98**	5.01*	0.40 ^{ns}	1.06 ^{ns}	0.50 ^{ns}	0.09 ^{ns}
Regression	2	171.56**	114.38**	52.63**	7.34**	65.63**	66.33**
Error	13	0.4540	0.000014	0.0000081	0.6546	0.1380	0.1193
Cropping systems							
Intercropping		21.76a	0.119a	0.124a	37.96a	6.92a	8.98a
Monocropping		19.13a	0.104b	0.121a	38.54a	6.66a	8.87a
CV (%)		8.94	10.51	8.07	2.87	10.66	8.27

† ** = P<0.01; * = P<0.05; ns = P>0.05. *Means followed by different lowercase letters in the column differ statistically from each other by the F test at the 5% probability level.

1.27 and 1.30, in the combinations of equitable amounts of the green manure's biomass and lettuce population densities of 65 t/ha and 300 thousand plants/ha, respectively (Figures 3A, 3B and 3C). These results indicate that the use of high population density of the lettuce crop (secondary crop) did not result in a negative effect on the intercropped system with radish, mainly in terms of competitive pressure for solar radiation, nutrients and other environmental resources. Balasubramaniyan & Palaniappan (2001) report that the population of plants in intercropped systems depends on the type and habit of crops growth, soil fertility, water and other factors necessary for growth. In the case under study, the architecture and morphology of radish and lettuce crops are completely different with regard to the demand for environmental resources, as they demand their needs at different times and occupied spaces.

High SPI value (15.37 t/ha) obtained in the combination of 65 t/ha of green manure biomass with 300 thousand lettuce plants/ha demonstrates the agronomic efficiency of the intercropped system of radish with lettuce in this combination in relation to the monocropping systems of these cultures. Likewise, the high LEC value (1.27) obtained, expressed the same agronomic efficiency of the intercropping of these two vegetables in the same combination of treatment-factors. When the LEC value is greater than 0.25, the intercropping system presents a production advantage in relation to the crop monocultures (Pinto *et al.*, 2012).

It is also possible to register by the MER value (1.30) that the agronomic efficiency of the radish and lettuce intercropping was translated into economic terms through MER. According to Afe & Atanda (2015), when MER is greater than 1.0, the intercropping systems are considered more profitable compared to monocultures. This superiority of MER can also be attributed to the complementary nature of the cultures involved. These results corroborate those obtained by Lino *et al.* (2021) studying the intercropping of beet and

Table 3. F values of the system productivity index (SPI), land equivalent coefficient (LEC) and monetary equivalent ratio (MER) of radish intercropped with lettuce at different equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and at different population densities of lettuce. Mossoró, UFERSA, 2020-2021.

Sources of variation	DF	SPI	LEC	MER
Blocks	3	0.07 ^{ns}	0.06 ^{ns}	0.08 ^{ns}
Amounts of <i>M. aegyptia</i> and <i>C. procera</i> biomass (A)	3	4.85 ^{**}	9.34 ^{**}	32.00 ^{**}
Population densities of lettuce (D)	3	124.73 ^{**}	144.64 ^{**}	232.02 ^{**}
A x D	9	0.84 ^{ns}	1.17 ^{ns}	1.50 ^{ns}
Regression	2	190.19 ^{**}	199.86 ^{**}	190.02 ^{**}
Error	13	0.2233	0.003624	0.002101
CV (%)		7.89	14.88	6.72

** = P<0.01; ns = P>0.05.

arugula under green manure and arugula planting densities in the semi-arid region of the Northeast, where they obtained a MER value of 1.56 with the combination of equitable biomass amounts of hairy woodrose and roostertree of 65 t/ha and of 1,000 thousand plants/ha of arugula, a result similar to that obtained in this research.

These agro-economic indexes obtained as a function of the equitable biomass amounts of the green manures are due in part to the good nutritional support provided by the mixture of the manures, which were able to efficiently meet the needs of crops, especially when expressed their productive potential in a situation of high population density of a crop. It is known that green manures from regional or non-regional plant biomass increase not only soil organic matter and nutrient content, but also improve soil structure, aeration and water storage capacity, thus contributing to chemical physical and biological soil properties (Silva *et al.*, 2020). Green manures can also provide nutrient cycling in the soil, bringing deeper nutrients to the surface.

Finally, we can infer that the greatest agro-economic benefits of the radish-lettuce intercropping were obtained with SPI of 15.37 t/ha, LEC of 1.27 and MER of 1.30, respectively, in the combination of 65 t/ha of the properties, biomass with the lettuce population density of 300 thousand plants/ha. The optimized maximum commercial productivity

of radish roots in the intercropping system was 8.45 t/ha in the combination of the biomass amount of 20 t/ha of properties, and lettuce population density of 300 thousand plants/ha, while the maximum lettuce leaf productivity optimized in the intercropping was 17.72 t/ha, in the combination of the green manure biomass amount of 65 t/ha and population density of 300 thousand plants/ha of lettuce. The use of spontaneous species from the Caatinga biome as green manure in the radish-lettuce intercropping provides agro-economic benefits in semi-arid environment.

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