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Agro-economic viability of lettuce-beet intercropping under green manuring in the semi-arid region

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ABSTRACT

Producers who practice intercropped systems of leafy vegetables with tuberous ones, generally seek for systems that provide high productivity, greater diversification of production, high quality products and mainly agroeconomic return. Therefore, the objective of this work was to assess whether there is agro-economic viability of lettuce bi-cropping in intercrop with beet, under different equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass (20, 35, 50 and 65 t ha^{-1} on dry basis) and population densities of lettuce (150, 200, 250 and 300 thousand plants of lettuce ha^{-1}), combined with 500 thousand plants per hectare of beet in two years of cultivation in semi-arid environment. Productivity of lettuce leaves and commercial productivity of beet roots were evaluated, as well as the agronomic indices: land equivalent ratio (LER), area-time equivalent ratio (ATER), productive efficiency index (PEI), score of the canonical variable (Z), actual yield loss (AYL), and the economic indicators: gross income (GI), net income (NI), monetary advantage (MA) and rate of return (RR). The highest agro-economic returns of the lettuce-beet intercropping were achieved with LER and ATER of 2.59 and 1.39; PEI and Z of 0.97 and 2.32; and AYL of 10.66; and GI, NI and MA of 94,742.89; 59,121.45; 56,631.98 R$ ha^{-1} and RR of R$ 2.75 for each real invested, respectively, in the combination of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass and lettuce population density 300 thousand plants per hectare. Beet was the dominant crop and lettuce the dominated one. The lettuce and beet intercropping is highly viable when properly manured with biomass of *M. aegyptia* and *C. procera*, as they express agronomic and economic viability and sustainability in semi-arid environment.

Keywords: *Lactuca sativa*, *Beta vulgaris*, *Merremia aegyptia*, *Calotropis procera*, mixed-cropping revenues.

RESUMO

Viabilidade agroeconômica do consórcio alface-beterraba sob adubação verde no semiárido

Produtores que praticam sistemas consorciados de hortaliças folhosas com tuberosas geralmente buscam sistemas que proporcionem alta produtividade, maior diversificação da produção, produtos de alta qualidade e principalmente retorno agroeconômico. Esse trabalho teve como objetivo avaliar se há viabilidade agroeconômica do bicultivo de alface em consórcio com beterraba sob diferentes quantidades equitativas de biomassa de *Merremia aegyptia* e *Calotropis procera* (20, 35, 50 e 65 t ha^{-1} em base seca) e densidades populacionais de alface (150, 200, 250 e 300 mil plantas de alface ha^{-1}), combinadas com 500 mil plantas por hectare de beterraba em dois anos de cultivos em ambiente semiárido. A produtividade de folhas de alface e a produtividade comercial de raizes de beterraba foram avaliadas, bem como, os indices agronômicos: relação equivalente de terra (RET), razão de área equivalente no tempo (RAET), indice de eficiência produtiva (IEP), escore da variável canônica (Z) e perda de rendimento real (PRR) e os indicadores econômicos: renda bruta (RB), renda liquida (RL), vantagem monetária (VM) e taxa de retorno (TR). Os maiores retornos agroeconômicos do consórcio alface-beterraba foram alcançados com RET e RAET de 2,59 e 1,39; IEP e Z de 0,97 e 2,32; PRR de 10,66, e RB, RL e VM de 94.742,89; 59.121,45 e 56.631,98 R$ ha^{-1} e TR de R$ 2,75 para cada real investido, respectivamente, na combinação de 65 t ha^{-1} de biomassa de *M. aegyptia* e *C. procera* e densidade populacional de alface de 300 mil plantas por hectare. A beterraba foi a cultura dominante e a alface a dominada. O consórcio de alface e beterraba é altamente viável quando adequadamente adubado com biomassa de *M. aegyptia* e *C. procera*, pois expressam viabilidade agronômica e econômica e sustentabilidade em ambiente semiárido.

Palavras-chave: *Lactuca sativa*, *Beta vulgaris*, *Merremia aegyptia*, *Calotropis procera*, receitas em cultivo consorciado.

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Intercropping system is a production alternative used by producers in the semi-arid tropic, with the aim of increasing the productivity of agricultural areas and the income of the producer, improving soil protection and diversifying agricultural production. It consists of the simultaneous cultivation of two or more crops in the same agricultural year, in the same area, so that the cultures share that same area for a significant period of their cultivation cycles. The intercropping of tuberous vegetables with leafy crops has shown satisfactory results regarding the efficient use of land (Bezerra Neto *et al*., 2012; Silva *et al*., 2017; Carvalho *et al*., 2018).

However, the efficiency of these cropping systems is conditioned by a series of important production factors that must be well managed, among which stand out: crops, fertilization, plant population, among others, so that these systems are pointed out as a more advantageous practice than monoculture. An example of an appropriate strategy of intercropping is not to have crops that compete with each other for physical space, nutrients, water or sunlight, that is, to plant a deep-rooted crop with a shallow-rooted crop, or to plant a higher crop with a smaller crop that requires partial shade. This strategy applies to growing beet with lettuce.

Regarding fertilization, this production factor needs special attention for what type of fertilizer should be used for the good performance of the crops involved in the intercropped system. In the cultivation of leafy vegetables with tuberous ones, satisfactory results have been obtained in intercropped systems, using green manures from the Caatinga biome, such as *Merremia aegyptia* (hairy woodrose) (Oliveira *et al*., 2017a; Silva *et al*., 2018) and *Calotropis procera* (rooster tree) (Oliveira *et al*., 2015; Nunes *et al*., 2018). These manures provide nutritional benefits for the soil, promote increased organic matter, improved water infiltration in the soil, increase in effective CEC, decrease in potential acidity, consequently increase in the base sum (Ambrosano *et al*., 2005), reduction of macro and micronutrient deficiency, because, when properly managed, they make available the nutrients of the organic matter needed for the crops (Zandvakili *et al*., 2017).

Another important factor for the success of the intercropping is the planting density, which directly influences the growth and development of the plants, dictated by the intra- and interspecific competition for environmental resources; thus, affecting the production of crops and their components (Lopes *et al*., 2008). Andrade Filho *et al*. (2020), working with coriander and arugula intercropping with beet, obtained greater profitability with a density of 200 thousand plants per hectare of each leafy vegetable combined with the density of 500 thousand plants per hectare of beet fertilized with the amount of *C. procera* biomass of 45 t ha^{-1}.

For the determination of efficiency in intercropped cropping systems based on production factors such as crop type, fertilization levels and population densities, several indexes and indicators have been used to quantify and express the benefits of the association, as well as the crop responses to intra and interspecific competition. Among the agronomic indices are the land equivalent ratio (Silva *et al*., 2018), area time equivalency ratio (Pinto *et al*., 2011), productive efficiency index, score of the canonical variable (Lima *et al*., 2014) and the crops aggressivity (Cecílio Filho *et al*., 2015). Among the economic indicators are gross income, net income, monetary advantage and rate of return (Oliveira *et al*., 2012; Gebru, 2015).

Thus, the objective of the present study was to assess whether there is agro-economic viability of lettuce bi-cropping in intercrop with beet, under different equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass (20, 35, 50 and 65 t ha^{-1} on dry basis) and population densities of lettuce (150, 200, 250 and 300 thousand plants of lettuce ha^{-1}), combined with 500 thousand plants per hectare of beet in two years of cultivation in semi-arid environment.

MATERIAL AND METHODS

Sites, climate and soil

Field experiments were conducted in different experimental areas at the Rafael Fernandes Experimental Farm of the Federal Rural University of Semi-Arid (FRUSA), located in the Lagoinha district, 20 km from the municipality of Mossoró-RN, Brazil (5º11'S, 37º20'W, 80 m altitude) from September to December 2018 and from August to November 2019. The climatic classification of the region, according to Köppen, is BShw, dry and very hot, with two climatic seasons. During the experimental periods, the recorded average values for minimum and maximum temperatures, relative humidity and precipitation for the cropping years 2018 and 2019 were respectively: 27.8 and 27.1°C; 33.2 and 32.9°C; 66.2 and 67.1% and 0.4 and 4.4 mm.

The soils in the areas were classified as Eutrophic Red-Yellow Argisols (Santos *et al*., 2018). Before the installation of the experiments, soil samples were taken at a depth of 0-20 cm, air-dried and sieved through a 2 mm sieve. Subsequently, the samples were analyzed at the Soil Fertility and Chemistry Laboratory at FRUSA, obtaining the following results: In the 2018 crop: pH= 8.10, electrical conductivity (EC)= 0.24 dSm^{-1}, organic matter (OM)= 4.97 g kg^{-1}, N= 0.35 g kg^{-1}, P= 22.80 mg dm^{-3}, K= 64.70 mg dm^{-3}, Na= 32.70 mg dm^{-3}, Ca= 3.28 $cmol_c$ dm^{-3}, Mg= 0.78 $cmol_c$ dm^{-3}, Cu= 0.10 $cmol_c$ dm^{-3}, Fe= 1.91 $cmol_c$ dm^{-3}, Mn= 11.67 $cmol_c$ dm^{-3} and Zn= 2.63$cmol_c$ dm^{-3}; and in the 2019 crop: pH= 7.10, EC= 0.10 dSm^{-1}, OM= 5.27 g kg^{-1}, N= 0.28 g kg^{-1}, P= 22.00 mg dm^{-3}, K= 69.50 mg dm^{-3}, Na= 26.70 mg dm^{-3}, Ca= 2.70 $cmol_c$ dm^{-3}, Mg= 0.50 $cmol_c$ dm^{-3}, Cu= 0.24 $cmol_c$ dm^{-3}, Fe= 2.10 $cmol_c$ dm^{-3}, Mn= 12.17 $cmol_c$ dm^{-3} and Zn= 5.57 $cmol_c$ dm^{-3}.

Experimental procedure, treatments and cultivars

The experimental design used was of complete randomized blocks, with the treatments arranged in a 4 x 4 factorial scheme, with four replications. The first factor was constituted by four equitable amounts of *M. aegyptia* and *C. procera* biomass (20, 35, 50 and 65 t ha^{-1} on a dry basis), and the second factor by four lettuce population densities in bi-cropping (150, 200, 250, and 300 thousand plants ha^{-1} in each cropping) in two cropping years. In each block, single plots of lettuce and beet were planted with equitable amounts of *M. aegyptia* and *C. procera* biomass optimized by the research to obtain the agronomic and economic indexes of the intercropped systems. The recommended population densities for single cropping beet and lettuce in the region are 500 and 250 thousand plants ha^{-1}, respectively (Silva *et al*., 2011; Paula *et al*., 2017). In the intercropped systems, the same population density as beet from single cropping was used. The beet cultivar was 'Early Wonder' and the lettuce cultivar 'Tainá'.

The intercropped cultivation was established in alternating strips of the component crops, where half of the area was occupied by the beet and the other half by lettuce. In each plot, the alternating strips consisted of four rows, flanked by two rows of lettuce on one side and two rows of beet on the other side, used as borders. The total area of the plot was 2.88 m^2 (2.40 x 1.20 m), with a harvested area of 1.60 m^2 (1.60 x 1.00 m). The harvested area consisted of the two central strips of plants, excluding the first and last plants of each row of strips used as borders.

The population densities of crops and the spacings used in intercropping systems and in the single crop of beet and lettuce crops are shown in Table 1.

Management and cultural practices

Before the installation of the experiments in the experimental areas, the soils were prepared starting with the mechanical cleaning of the areas with the aid of a tractor with a coupled plow, followed by a harrowing and mechanized lifting of the beds with a rotary hoe. Subsequently, a 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 in the soil.

The green manures *Merremia aegyptia* and *Calotropis procera* are spontaneous species from the Caatinga biome. The *M. aegyptia* is a species native to northeastern Brazil of the family Convolvulaceae; succulent, with a pleasant smell, much appreciated by animals. It is an annual climber plant, herbaceous, with a cylindrical, striated and glabrous stem, with shaggy pubescence. The leaves are yellowish, membranous and alternating; the inflorescence consists of branches of 6-9 lily-like flowers; and the fruit is a subglobose capsule. This plant can produce 36 t ha^{-1} of green biomass in the rainy season, which in terms of dry basis contains 2.62% N, 0.17% P, 1.20% C, 1.2% K, 0.90% Ca and 1.08% Mg, making this plant a good source of green manure to be used on family farms (Linhares *et al*., 2009). It is widely distributed in northeastern Brazil, found in forests, fences, clearings, swiddens and fields and grows in soils of different textures (Góes, 2007). There is no danger of the extinction of the species, as it is a plant native to the northeast, where the aerial part is usually collected at the beginning of flowering, leaving the part below the ground to regrow under favorable conditions of water supply.

On the other hand, *C. procera* is a spontaneous species of the Caatinga biome, introduced, belonging to the Apocynaceae family of shrubby or subarboreal size, with more or less 2.5 m in height, reaching up to 6.0 m. It has one or a few stems (stem) and few branches, it has an erect habit, usually caulescent. The branches, leaves, peduncles and fruits are covered with wax, which is more intense in the younger parts. Well-developed root system, with taproot that can reach 1.7 to 3.0 m in sandy desert soils. It is a species that spreads easily through the wind. Its propagation can be by vegetative parts or by seeds. The plant remains green throughout the year, even in periods of long drought (Costa *et al*., 2009), producing an amount of 51 t ha^{-1} of green biomass containing, on a dry basis, 1.53% N, 4.0% P, 1.57% K, 0.93% Ca and 0.73% Mg (Oliveira & Souto, 2009; Bezerra Neto *et al*., 2019). It is a species that develops in environments with low soil water content, resisting drought, which seems to us that its cultivation, especially in the semi-arid region, would minimize the problem of food shortages in the driest period of years. There is no danger of the extinction of the species, as it is a plant adapted to the northeast Brazil, where generally when the aerial part is cut, it regrows sixty days after cutting, as it is considered a perennial plant.

Regarding the access of these two species to be used as green manure, the only cost involved in the acquisition of these materials would be that arising from the collection service, short distance transport and crushing of the material to be used for incorporation into the soil.

The green manures *M. aegyptia* and *C. procera* were collected in rural areas located in the municipality of Mossoró-RN and in the neighborhood. After that, they were crushed in a conventional forage machine, obtaining fragmented particles around 2.0 to 3.0 cm, dehydrated in sunlight for a period of three to five days until reaching a content of approximately 10% moisture. Samples of these materials were subjected to laboratory analysis providing the following results. In the 2018 cropping, for *M. aegyptia*, the contents of N, P, K, Mg and Ca were 16.60; 2.79; 37.80; 7.07 and 19.35 g kg^{-1}, and for *C. procera* 21.90; 1.92; 20.90; 9.22 and 17.00 g kg^{-1}. In the 2019 cropping, for *M. aegyptia*, the contents of N, P, K, Mg and Ca were 15.30; 4.00; 25.70; 7.03 and 9.30 g kg^{-1}, and for *C. procera* 18.40; 3.10; 24.50; 13.50 and 16.30 g kg^{-1}, respectively.

Two incorporations with the amounts of the green manures were carried out, the first one at 20 days before planting the crops, with 50% of the equitable amounts of *M. aegyptia* and *C. procera* and the remaining 50% was incorporated at 35 days after the planting, according to Sousa's methodology (2017). Between the rows of vegetables, 15 cm furrows were made to incorporate the amounts of green manures.

Beet was sown on September 11, 2018 in the first agricultural year and on August 27, 2019 in the second agricultural year, in 3.0 cm deep holes, with two to three seeds per hole. Two crops of lettuce were grown each year of cultivation. Lettuce was sown in 200-cell polystyrene trays with three seeds per cell and the seedlings were transplanted 20 days later to the field, in 5.0 cm deep holes in the beds. The first lettuce transplant of the year 2018 was carried out on the same day as the sowing of the beet and the second transplant was carried out on November 6, 2018. In 2019, the lettuce was transplanted on the same day as the sowing of the beet and the second transplant on October 21, 2019. The beet thinning was carried out seven days after planting, leaving one plant per hole. The lettuce thinning was also carried out at seven days, leaving a seedling per cell.

The irrigation of the vegetables was carried out in a micro-sprinkler system with a daily irrigation shift, divided into two applications, morning and afternoon (Martins *et al*., 2018). The amount of water supplied was determined by the values of the beet cultivation coefficient (average Kc = 0.83) (Oliveira Neto *et al*., 2011), with an irrigation depth of approximately 8 mm day^{-1}. Weed control was carried out, whenever necessary, by means of manual harvesting of the plants. No chemical pest and disease control method was used.

The beet harvests were carried out at 70 and 71 days after sowing (DAS) in the first and second cropping year, while the two lettuce harvests were carried out at 29 DAS in the first cropping year, and at 28 and 29 DAS in the second cropping year.

The commercial productivity of beet roots (larger roots >7 cm; extra AA roots ≥6 to <7 cm; extra A ≥5 to <6 cm; extra >4 to <5 cm) and the productivity of lettuce leaves were quantified and expressed in t ha^{-1}. Lettuce classification was based on leaf color, quality characterization and leaf shape homogeneity, since in semi-arid climate it does not form a head due to high temperature and shortening of the cycle (HortiBrasil, 2019). The agro-economic efficiency of the beet and lettuce intercropped systems was assessed by the agronomic indices and economic indicators described below.

Evaluated variables

The agronomic indices evaluated in the studied intercropped systems were: land equivalent ratio (LER), area time equivalent ratio (ATER), productive efficiency index (PEI), score of the canonical variable (Z), the aggressivity of beet (A_b) over the lettuce and the aggressivity of the lettuce (A_l) over beet, and competitive ratio (CR).

LER was obtained by the following expression used by Silva *et al*. (2018). LER = $(Y_l1_b/Y_{ll}1) + (Y_l2_b/Y_{ll}2) + (Y_{bl}/Y_{bb})$, where Y_l1_b, Y_l2_b are the lettuce productivities in the first and second cropping intercropped with beet and Y_{bl} is the productivity of beet intercropped with lettuce. $Y_{ll}1$ and $Y_{ll}2$ are the productivities of lettuce in single cropping in the first and second cultivation, and Y_{bb} the productivity of beet in single cropping. It is defined as the relative area of land under single planting conditions, which is required to provide the productivity achieved in the intercropping.

ATER was determined by the formula used by Pinto *et al*. (2011). ATER = $[(LERl_1 \times Tl_1) + (LER_l2 \times Tl_2) + (LER_b \times T_b)]/T$, where, $LERl_1$ and $LERl_2$ are the lettuce land equivalent ratios in the first and second cropping intercropped with beet and LER_b is land equivalent ratio of beet intercropped with lettuce. Tl_1 and Tl_2 represent the number of days from planting until the lettuce harvest in the first and second cropping and T_b represents the number of days from planting until the beet harvest, and T represents the total time of the intercropped system of the lettuce with beet.

The PEI for each treatment was calculated using the DEA (Data Envelopment Analysis) model with constant returns to scale (Mello & Gomes, 2013), since there is no evidence of significant scale differences. This model has the following mathematical formulation:

$$\text{Max } z = \sum_{j=1}^{r} \mu_j x_{jo}$$

subject to

$$\sum_{i=1}^{s} \nu_i w_{io} = 1 \quad ;$$

$$\sum_{j=1}^{r} \mu_j x_{jk} - \sum_{i=1}^{s} \nu_i w_{ik} \leq 0,$$

k = 1 ... n; μ_j, $\nu_i \geq 0$, i = 1… s, j = 1… r, in which w_{ik}: value of input i (i = 1 ... s), for treatment k (k = 1 ... n); y_{jk}: value of output j (j = 1 ... r), for treatment k; ν_i and μ_j: weights assigned to inputs and outputs, respectively; o: treatment under analysis.

The evaluation units were the treatments (the intercrops), in a total of 16. As outputs, lettuce productivities were used in the first and second cropping and the commercial productivity of beet. To assess the performance of each plot, we considered that each one uses a single resource with unitary level, since the outputs incorporated the possible inputs. As input the values of the rate of return were used. This model is equivalent to an additive multicriteria model, with the particularity that the alternatives themselves assign weights to each criterion, ignoring any opinion of an eventual decision maker, that is, DEA is used as a multicriteria tool and not as a classic efficiency measure.

The Z score for each treatment was obtained using an equation from the bivariate analysis of variance to complete randomized complete blocks design of the commercial productivities of beet roots and of the leaves of lettuce.

The actual yield loss (AYL) was obtained by the following expression used by Cecílio Filho *et al*. (2015). AYL = $AYL_b + AYL_l$; $AYL_b = [\{(Y_{bb}/Z_{bl})/(Y_b/Z_{bb})\}-1]$ and $AYL_l = [\{(Y_{lb}/Z_{lb})/(Y_{ll}/Z_{ll})\}-1]$, where, AYL is the actual yield loss of the intercropped system. AYL_b and AYL_l are the actual yield losses of the beet and lettuce, and Y_{lb} and Y_{bl} are the productivities of the lettuce in intercropping with the beet and of the beet in intercropping with the lettuce. Y_{ll} and Y_{bb} are the productivities of lettuce and beet in single cropping. Z_{bb} and Z_{ll} are the planting proportions of beet and lettuce in single cropping, Z_{bl} and Z_{lb} are the proportions of the beet intercropping with lettuce and of the lettuce with beet.

The A is an index to indicate how much the relative increase in production of a component crop *b* (in this case, beet) is greater than that of component crop *l* (lettuce) in an intercropped system. This index was proposed to measure the dominance of one culture over the other. This index is given by the following expression used by Cecílio Filho *et al*. (2015). $A_{lb} = (Y_{lb}/Y_{ll} \times Z_{lb}) - (Y_{bl}/Y_{bb} \times Z_{bl})$ and $A_{bl} = (Y_{bl}/Y_{bb} \times Z_{bl}) - (Y_{lb}/Y_{ll} \times Z_{lb})$). Y_{lb} and Y_{bl} are the productivities of lettuce intercropped with beet and of beet intercropped with lettuce, and Y_{ll} and Y_{bb} are the productivities of lettuce and beet in single crops. Z_{bl} is the proportion of planting of the beet in intercropping with lettuce, and Z_{lb} is the proportion of planting of the lettuce in intercropping with beet.

The Competitive Ratio (CR) measures the degree that one crop competes with the other, presenting the basis of its calculation as a function of the productivity of the main crop and consort in intercrop and single cropping as well as the space used in the cultivated field by both. This index indicates the number of times that one component is more competitive than another (Pinto *et al*., 2011). The expression of the competitive ratio (CR) of the intercropped system is: CR = CR_l x CR_b. The expressions for CR_l and CR_b are: $CR_{bl} = [(Y_{bl}/(Y_{bb} \times Y_{bl}) + [(Y_{lb}/(Y_{ll} \times Y_{lb}))$ and $CR_{lb} = [(Y_{lb}/(Y_{ll} \times Y_{lb}) + (Y_{bl}/(Y_{bb} \times Y_{bl}))]$. CR_{bl} and CR_{lb} are competitive ratios of the lettuce over beet and beet over lettuce. Y_{bl} and Y_{lb} are the productivities of beet and lettuce, in the association, respectively, and Y_{bb} and Y_{ll} are the productivities of beet and lettuce in single cropping. Z_{bl} and Z_{lb} are the planting proportions of the intercropping of beet with lettuce and lettuce with beet. In an intercropping, the crop with the largest CR has the greatest ability to use environmental resources when compared to the other component culture.

The economic indicators evaluated in the intercropping systems of beet and lettuce studied were: gross income (GI), net income (NI), rate of return (RR) and monetary advantage (MA). The GI was determined by multiplying the value of the production obtained per hectare by the current price paid to the producer at the market level in the region, in March, 2021. The NI was calculated by subtracting the production total costs (TC) from inputs and services from the GI, where NI = GI - TC. The RR was obtained by the ratio between the GI and the TC, that is, RR = GI/TC, which corresponds to how much reais are obtained in return for each real invested. Finally, the MA was determined by the expression: MA = GI x (LER -1/LER).

Statistical analysis

Univariate analysis of variance for the randomized complete blocks design in a factorial scheme was used to evaluate the agronomic indices and economic indicators determined in the intercropped systems of beet and lettuce, using the SISVAR software (Ferreira, 2011). Due to the homogeneity of the variances between the cropping years, an average of these indexes and indicators was made between the cropping years. After that, a regression analysis was performed on each index or indicator, where a procedure for adjusting a response surface was adjusted as a function of the equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil and lettuce population densities, through the Table Curve 3D software (Systat Software, 2021).

RESULTS AND DISCUSSION

Biological advantages

The mean productivities data of lettuce and beet used to calculate the agronomic and economic indices are presented in Table 2. Significant interaction between the treatment-factors, equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil and population densities of lettuce in bi-cropping were recorded in the agronomic indices, land equivalent ratio (LER), area time equivalency ratio (ATER), productive efficiency index (PEI), score of the canonical variable (Z) and actual yield loss (AYL). There was no significant interaction in the beet aggressivity (A_b) over lettuce and in the lettuce aggressivity (A_l) over beet in the intercropped system and in the competitive ratio (Table 2).

However, a response surface was adjusted for all these agronomic efficiency indexes as a function of the treatment-factors, where the maximum values of LER, ATER, PEI, Z and AYL of 2.59, 1.38, 0.97, 2.32, and 10.66, respectively, were achieved by combining the equitable biomass amount of 65 t ha^{-1} of green manures with the lettuce population density of 300 thousand plants per hectare (Figures 1A to 1E). For the aggressivity of beet, the maximum value obtained was 0.60 in the combination of the equitable biomass amount of 42 t ha^{-1} of green manures with the lettuce population density of 155 thousand plants per hectare, and for the aggressivity of lettuce, the maximum value reached was -0.30 in the combination of the equitable biomass amount of 65 t ha^{-1} of green manures with the lettuce population density of 253 thousand plants per hectare (Figures 1F and 1G). From these 'A' results, it can be seen that beet was the dominant crop in the intercropping and lettuce was the dominated crop. This index is a good indicator of the degree of complementarity between the component cultures, as it dictates intra and interspecific competition between them in the intercropped system.

The maximum competitive ratio of 2.95 was recorded in the combination of the equitable amount of biomass of 20 t ha^{-1} of green manures with the lettuce population density of 150 thousand plants per hectare (Figure 1H). The CR provides the exact degree of competition by indicating the number of times in which the dominant species is more

Table 1. Description of population densities and spacings of the beet and lettuce used in the intercropping and single cropping systems. Mossoró, UFERSA, 2019.

Population densities of the crops in intercropping (thousand plants ha^{-1})		Spacings (m)	
Beet	**Lettuce**	**Beet**	**Lettuce**
500	150	0.20 x 0.05	0.20 x 0.166
500	200	0.20 x 0.05	0.20 x 0.125
500	250	0.20 x 0.05	0.20 x 0.100
500	300	0.20 x 0.05	0.20 x 0.080
Population densities of the crops in single cropping (thousand plants ha^{-1})			
Beet	500	0.20 x 0.10	-
Lettuce	250	-	0.20 x 0.20

competitive than the dominated species. In an intercropped system, the crop with the higher CR makes better use of the environmental resources.

These results indicate the best use of environmental resources due to the adequate management of the production factors, amounts of green manures and population densities of lettuce plants, which would provide chemical, physical and biological improvements to the soil, thus enabling the achievement of agronomic efficiency maximum of the intercropped system. Green manure, in addition to providing the necessary nutrients for the development of crops, increases the content of organic matter, decreases the levels of erosion, increases the permeability and activity of the soil microbiota, increasing the availability of nutrients and reduces the amount of invasive plants (Graham & Haynes, 2006; Batista *et al*., 2016; Oliveira *et al*., 2017a).

On the other hand, it is known that the competition between component crops of an intercropping is regulated through morphophysiological and management differences with population density, amount of fertilizers and proportion of the crops in the system. In other words, they are factors that limit the growth and development of cultures (Morgado & Willey, 2008). Thus, the increase in the population density of lettuce and the greater total absorption of nutrients by the component crops in the system are presented as the main cause of obtaining agronomic advantages in the intercropped system.

This agronomic advantage of the intercropping was recorded explicitly through the values obtained in LER, ATER, PEI, Z and As, with values higher than those of single cropping of beet and lettuce crops, indicating that there was a complementarity and an ideal competitiveness between component crops, consequently translating into better use of environmental resources.

One of the challenges in intercropping leafy vegetable with tuberous is whether there are agronomic advantages in this association. Oliveira *et al*. (2017a), intercropping arugula and coriander with carrot in strips in semi-arid environment manured with *M. aegyptia* under various combinations of population densities of the component crops, obtained the highest agronomic indices, LER (1.61), PEI (0.89) and Z (7.54) in the combination of population densities of 500, 250 and 500 thousand plants per hectare of arugula, carrot and coriander manured with 22 t ha^{-1} of *M. aegyptia* biomass incorporated into the soil.

On the other hand, Oliveira *et al*. (2017b), intercropping arugula and lettuce with carrot at the same environment manured with *C. procera* in different combinations of population densities of the component crops, obtained the highest agronomic indices, LER (1.96), PEI (0.85) and Z (1.34) in the combination of population densities of 500, 250 and 125 thousand plants per hectare of arugula, carrot and lettuce manured with 55 t ha^{-1} of *C. procera* biomass added to the soil.

Agronomic efficiency was registered both in the intercrop of carrot with arugula and coriander and of carrrot with arugula and lettuce. These results report the success of leafy vegetable intercropping with tuberous.

Economic returns

Significant interactions between the treatment-factors, equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil and population densities of lettuce in bicropping were

Table 2. F values for land equivalent ratio (LER), area time equivalency ratio (ATER), productive efficiency index (PEI), score of the canonical variable (Z), actual yield loss (AYL), aggressivity of the beet (A_b) over lettuce, aggressivity of lettuce (A_l) over beet, competitive ratio (RC), and mean commercial productivity of lettuce leaves and beet roots as a function of the equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass incorporated into the soil and population densities of lettuce in two cropping years. Mossoró, UFERSA, 2019.

Sources of variation	DF	LER	ATER	PEI	Z	AYL	A_b	A_l	RC
Blocks	3	1.94^{ns}	1.60^{ns}	1.78^{ns}	1.27^{ns}	1.51^{ns}	4.10*	4.10*	2.58^{ns}
Amounts of *M. aegyptia* and *C. procera* biomass (A)	3	208.14**	236.54**	136.82**	220.82**	211.00**	4.06*	4.06*	9.65**
Population densities of lettuce (D)	3	32.89**	34.41**	8.42**	31.15**	27.78**	1.35^{ns}	1.35^{ns}	8.32**
A x D	9	3.49**	3.18**	2.79*	3.99**	2.54*	1.71^{ns}	1.71^{ns}	1.45^{ns}
CV (%)		8.58	7.23	7.43	7.81	8.76	38.51	38.51	12.37

Population densities of lettuce (1,000 plants ha^{-1})	Mean commercial productivity of lettuce leaves and beet roots							
	20		35		50		65	
	Beet	Lettuce	Beet	Lettuce	Beet	Lettuce	Beet	Lettuce
150	5.67	15.47	10.91	20.59	11.34	25.94	14.73	26.35
200	8.01	15.32	10.52	23.90	14.73	28.23	20.82	31.56
250	8.70	17.16	14.46	25.49	20.57	29.33	28.43	31.85
300	9.62	20.16	14.82	26.36	18.23	28.43	22.26	30.49

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

recorded in the economic indicators, gross income (GI), net income (NI), monetary advantage (MA) and rate of return (RR), as shown in Table 3.

A response surface was adjusted for these interactions, where the maximum values of 94,742.89; 59,121.45 and 56,631.98 R$ ha^{-1} were obtained respectively for gross income, net income and monetary advantage in the population density of 300 thousand plants of lettuce ha^{-1}. The maximum

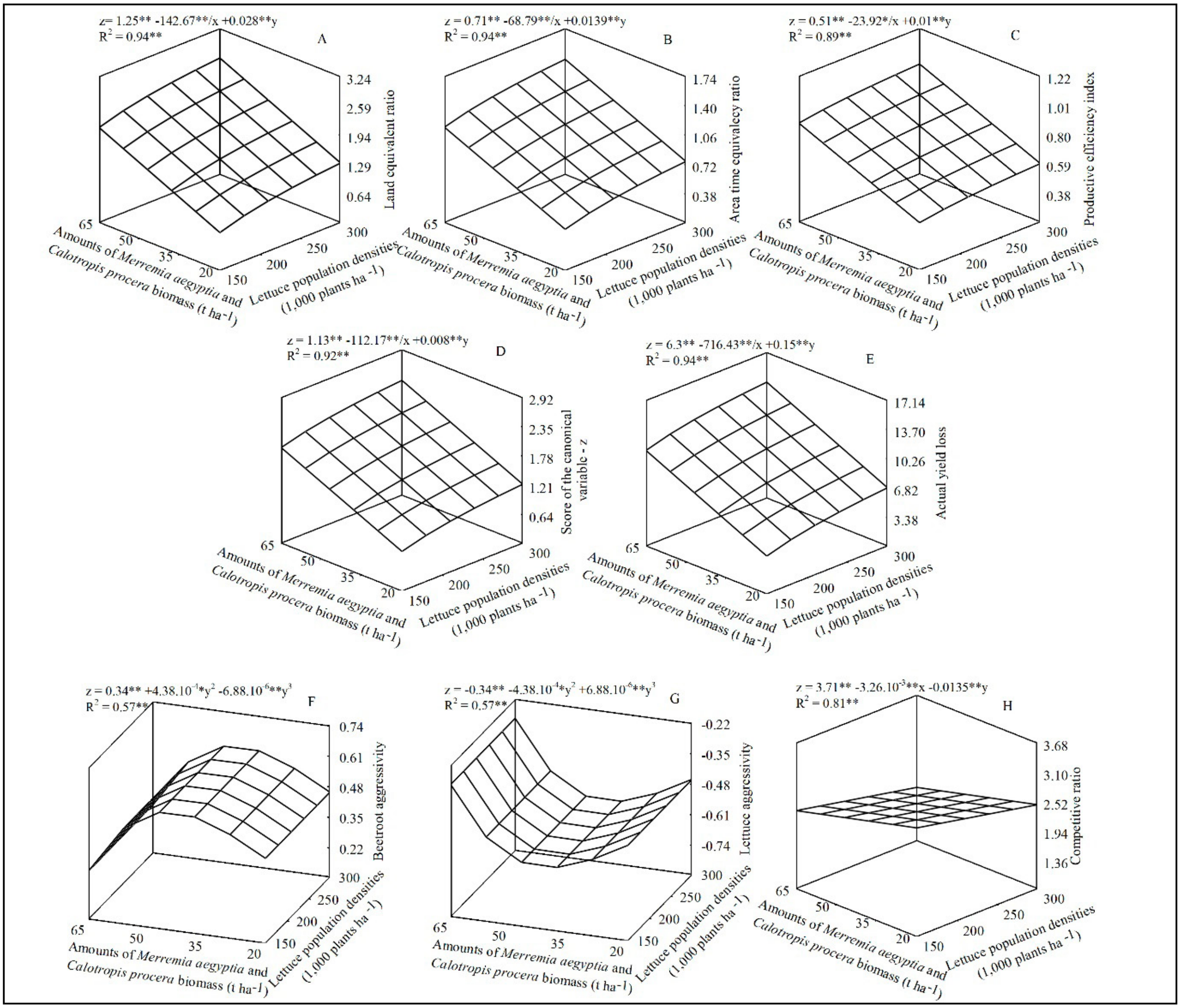

Figure 1. Land equivalent ratio (A), area time equivalency (B), productive efficiency index (C), score of the canonical variable Z (D), actual yield loss (E), aggressivity of beet (F), aggressivity of lettuce (G) and competitive ratio (H) of the lettuce in bicropping intercropped with beet in different combinations of equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass incorporated into the soil and population densities of lettuce in two cropping years. Mossoró, UFERSA, 2019.

Table 3. F values for gross income (GI), net income (NI), monetary advantage (MA) and rate of return (RR) for lettuce in bicropping intercropped with beet as a function of lettuce population densities and biomass amounts of *Merremia aegyptia* and *Calotropis procera* incorporated into the soil in two cropping years. Mossoró, UFERSA, 2019.

Sources of variation	DF	GI	NI	MA	RR
Blocks	3	1.22^{ns}	1.22^{ns}	1.77^{ns}	1.21^{ns}
Amounts of *M. aegyptia* and *C. procera* biomass (A)	3	232.75**	147.43**	232.11**	82.23**
Population densities of lettuce (D)	3	33.80**	14.23**	36.61**	6.09**
A x D	9	3.31**	3.31**	3.47**	3.08**
CV (%)		7.49	13.03	18.65	7.22

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

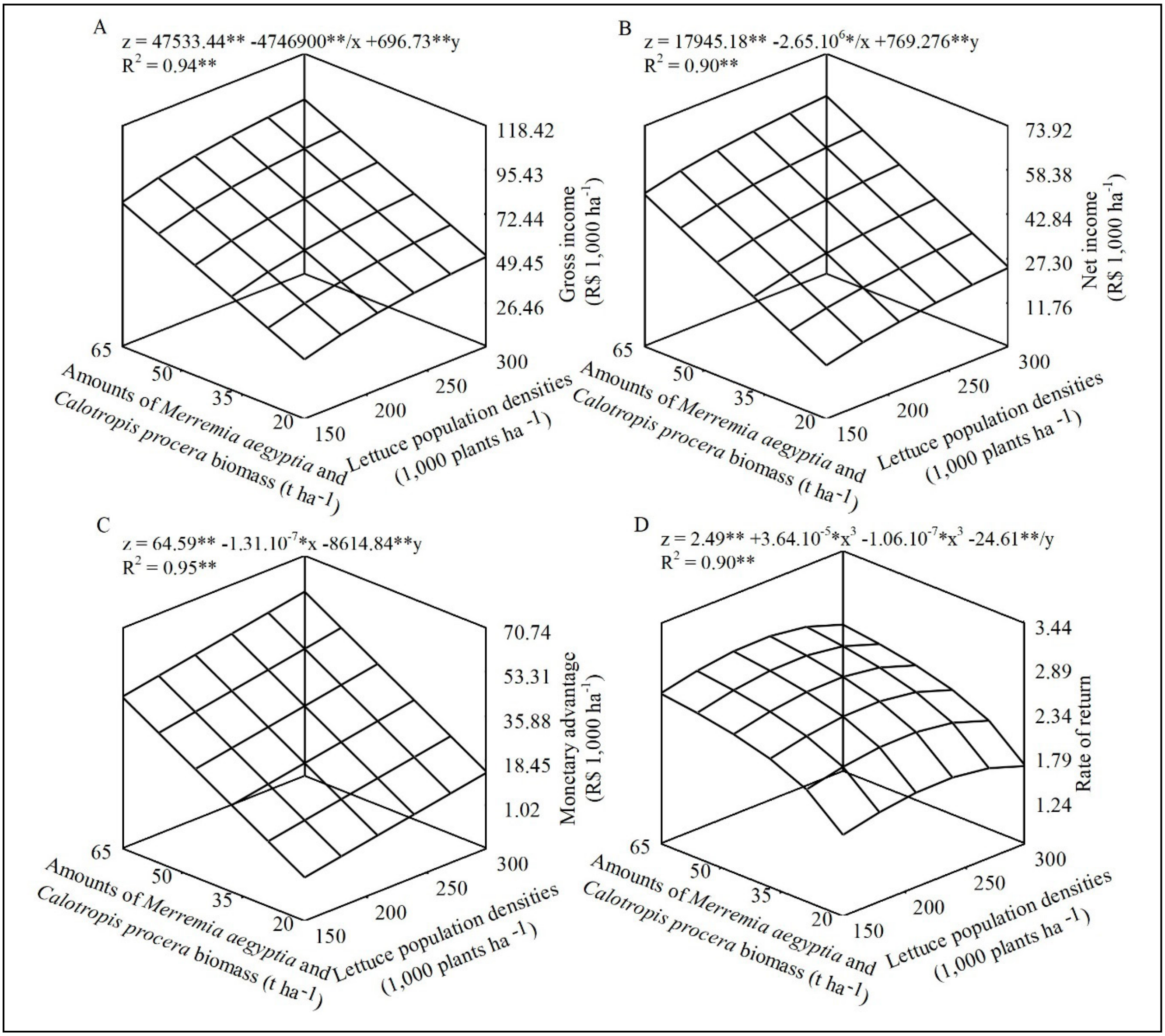

Figure 2. Gross income (A), net income (B), monetary advantage (C) and rate of return (D) of lettuce in bicropping, intercropped with beet in different combinations of equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass incorporated into the soil and lettuce population densities in two cropping years. Mossoró, UFERSA, 2019.

value of 2.75 for the rate of return was reached in the population density of 229 thousand lettuce plants, when manured with the equitable amount of biomass of 65 t ha^{-1} of the green manures *M. aegyptia* and *C. procera* incorporated into the soil (Figures 2A, 2B, 2C and 2D).

It is known that economic analysis complements the evaluation of agronomic/biological efficiency of the intercropped systems, as it considers, in addition to the physical production of crops, the price of products according to their commercial and quality classification and of the cropping season in the agricultural year. Gross income and monetary advantage is an indicator that represents the value of the combined production of the crops in each intercropping system, regardless of the production costs, that is, it depends exactly on the price that the production of the system is traded. Net income and the rate of return are indicators that depend on production costs, since they are standardized in terms of these costs. The higher their values, the greater the net advantage expressed by the intercropped system.

In general, the results of the economic indicators obtained in this research are highly promising in terms of economic advantage for the beet and lettuce intercropping. The net income and the rate of return express in monetary terms agronomic/biological advantage obtained in this intercropping as a function of the increase in the biomass equitable amounts of *M. aegyptia* and *C. procera* incorporated in the soil and the increase in lettuce population densities. They indicate that it is advantageous to combine beet with lettuce by manuring the intercropping organically with the green manures *M. aegyptia* and *C. procera*, but, properly managing the population density of the lettuce culture.

The maximum economic indicators obtained in this research with the beet intercropping with lettuce (GI = 94,742.89 R$ ha^{-1}; MA = 56,631.98 R$ ha^{-1}; NI = 59,121.45 R$ ha^{-1} and RR = R$ 2.75 for each real invested) were higher than those obtained by Oliveira *et al*. (2017b), where they obtained the following results: GI = 32,476.24 R$ ha^{-1}; NI = 11,674.49 R$ ha^{-1} and RR = R$ 1.65 for each real invested in the biomass amount of 55 t ha^{-1} of *C. procera* in the population densities of 500, 250 and 125 plants per hectare of arugula, carrot and lettuce.

These results were also superior to those obtained by Oliveira *et al*. (2017a), for GI = 18,771.13 R$ ha^{-1}; NI = 4,016.56 R$ ha^{-1} and RR = R$ 1.31 for each real invested in the biomass amount of 55 t ha^{-1} of *M. aegyptia* in the population densities of 500, 250 and 500 plants per hectare of arugula, carrot and coriander. These differences between the researches are due to the production costs of the tested treatments.

Under soil and weather conditions in this study, the highest agro-economic returns of the beet-lettuce intercropping were achieved for LER and ATER of 2.59 and 1.39; IA of 21.77; PEI and Z of 0.97 and 2.32, and for GI, NI and MA of 94,742.89; 59,121.45 and 56,631.98 R$ ha^{-1} and RR of R$ 2.75 for each real invested, respectively, in the combination of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass and lettuce population density of 300 thousand plants per hectare. The beet and lettuce intercropping is highly viable when properly manured with *M. aegyptia* and *C. procera* biomass, as they express agronomic and economic viability and sustainability in semi-arid environment. Beet was the dominant crop and lettuce the dominated one.

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