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Productive and agro-economic benefits in beet-lettuce intercropping under organic manuring and population densities

Benefícios produtivos e agroeconômicos no consórcio de beterraba-alface sob adubação orgânica e densidades de populacionais

Beneficios productivos y agroeconómicos en asociación de remolacha-lechuga bajo fertilización orgánica y densidades poblacionales

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Abstract
The use of a cropping system that provides producers with better land use, higher productivity per unit area, greater diversification in production, and consequently agro-economic advantages, has been the choice of vegetables producers. Therefore, the objective of this work was to evaluate the productive and agro-economic benefits of beet-lettuce intercropping under different equitable amounts of *Merremia aegyptia* and *Calotropis procera* biomass (20, 35, 50 and 65 t ha^{-1} on a dry basis) in different lettuce population densities (150, 200, 250, and 300 thousand plants ha^{-1}), in two cropping years in semi-arid environment. In the cultures and in the intercropping, the production and its components and the agro-economic indexes were evaluated. The maximum production of beet commercial roots in intercropping with lettuce was obtained with a productivity of 33.77 t ha^{-1} in the amount of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass incorporated into the soil and in the lettuce population density of 300 thousand plants per hectare, while the maximum lettuce leaf production was achieved with a productivity of 24.40 t ha^{-1} in the same combination of green manure amounts and lettuce population densities. The greatest agro-economic advantages of the beet intercropping with lettuce were achieved with a system productivity index (SPI) of 32.97 t ha^{-1}, land equivalent

coefficient (LEC) of 0.87 and a monetary equivalence ratio (MER) of 1.55, respectively, in the combination of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass with a lettuce population density of 300 thousand plants per hectare.
Keywords: *Beta vulgaris*; *Lactuca sativa*; *Merremia aegyptia*; *Calotropis procera*; Sustainability.

Resumo

A utilização de sistema de cultivo que proporcione aos produtores melhor aproveitamento da terra, maior produtividade por unidade de área, maior diversificação da produção e, consequentemente, vantagens agroeconômicas, tem sido a escolha dos produtores de hortaliças. Portanto, o objetivo deste trabalho foi avaliar os benefícios produtivos e agroeconômicos do consórcio beterraba-alface sob diferentes quantidades eqüitativas de *Merremia aegyptia* e *Calotropis procera* biomassa (20, 35, 50 e 65 t ha^{-1} em base seca) em diferentes densidades populacionais de alface (150, 200, 250 e 300 mil plantas ha^{-1}), em dois anos de cultivos em ambiente semiárido. Nas culturas e no consórcio, foram avaliados a produção e seus componentes e os índices agroeconômicos. A produção máxima de raízes comerciais de beterraba no consórcio com alface foi obtida com a produtividade de 33,77 t ha^{-1} na quantidade de 65 t ha^{-1} de biomassa de *M. aegyptia* e *C. procera* incorporada ao solo e na densidade populacional de alface de 300 mil plantas por hectare, enquanto a produção máxima de alface foi alcançada com produtividade de 24,40 t ha^{-1} na mesma combinação dos adubos verdes e densidades populacionais de alface. As maiores vantagens agroeconômicas do consórcio beterraba x alface foram alcançadas com índice de produtividade do sistema (IPS) de 32,97 t ha^{-1}, coeficiente equivalente de terra (CET) de 0,87 e razão de equivalência monetária (REM) de 1,55, respectivamente, na combinação de 65 t ha^{-1} de biomassa de *M. aegyptia* e *C. procera* com densidade populacional de alface de 300 mil plantas por hectare.
Palavras-chave: *Beta vulgaris*; *Lactuca sativa*; *Merremia aegyptia*; *Calotropis procera*; Sustentabilidade.

Resumen

El uso de sistema de cultivo que brinde a los productores un mejor uso de la tierra, mayor productividad por unidad de área, mayor diversificación en la producción y, en consecuencia, ventajas agro-económicas, ha sido la elección de los productores de hortalizas. Por lo tanto, el objetivo de este trabajo fue evaluar los beneficios productivos y agroeconómicos en asociación de remolacha-lechuga bajo diferentes cantidades equitativas de biomasa de *Merremia aegyptia* y *Calotropis procera* (20, 35, 50 y 65 t ha^{-1} en base seca) en diferentes densidades poblacionales de lechuga (150, 200, 250 y 300 mil plantas ha^{-1}), en dos años de cultivo en medio semiárido. En las culturas y en la asociación se evaluó la producción y sus componentes y los índices agroeconómicos. La producción máxima de raíces comerciales de remolacha en asociación con lechuga se obtuvo con una productividad de 33.77 t ha^{-1} en la cantidad de 65 t ha^{-1} de biomasa de *M. aegyptia* y *C. procera* incorporada al suelo y en la densidad poblacional de lechugas de 300 mil plantas por hectárea, mientras que la producción máxima de hojas de lechuga se logró con una productividad de 24,40 t ha^{-1} en la misma combinación de cantidades de abonos verdes y densidades poblacionales de lechuga. Las mayores ventajas agroeconómicas de la asociación de remolacha con lechuga se lograron con un índice de productividad del sistema (IPS) de 32,97 t ha^{-1}, coeficiente equivalente de tierra (CET) de 0,87 y una razón de equivalencia monetaria (REM) de 1,55, respectivamente, en el combinación de 65 t ha^{-1} de biomasa de *M. aegyptia* y *C. procera* con una densidad poblacional de lechuga de 300 mil plantas por hectárea.
Palabras clave: *Beta vulgaris*; *Lactuca sativa*; *Merremia aegyptia*; *Calotropis procera*; Sustentabilidad.

1. Introduction

Beet and lettuce represent a group of horticultural crops of economic, social and nutritional importance in the production systems of the semi-arid region of Northeast Brazil, where their crops are growing. Beet is rich in sugars, high in iron, both in roots and leaves, a good source of folate and vitamin C and its leaves are rich in potassium, calcium, iron and beta-carotene, while lettuce, a herbaceous plant rich in nutrients and chlorophyll, has the function of alkalinizing and detoxifying the body, mainly the liver. It is an important source of vitamins (A, C and niacin) and mineral salts (of sulfur, phosphorus, iron, calcium and silicon).

One of the forms of cultivation that increases the production of these vegetables per unit area is through the intercropping of crops, that is, cultivating two or more crops simultaneously in the same area of land (Almeida et al., 2015; Morais et al., 2018; Nascimento et al., 2018; Sousa et al., 2018). These crops are not necessarily sown at exactly the same time, and their harvest seasons may be completely different, but they are generally "simultaneous" for a significant part of their growing periods. In these circumstances, the intercropping can support the increase in aggregate production per unit of input, guarantee against crop failure and market fluctuations, meet food preferences and/or cultural demands, protect and improve soil quality and increase producer income (Rusinamhodzi et al., 2012).

One of the major challenges for the success of this combined production system is the choice of crops and of production factors such as fertilization and population densities, among others. It is known that beet and lettuce are two cultures considered as companions, that is, when grown together or close to each other, they help and benefit each other, enabling greater use of the cultivation area, inhibitory action on harmful or beneficial insects and some of them can improve soil quality (Andrade Filho et al., 2020). So, intercropping companion plants is a great way to avoid pesticides, contribute to biodiversity and increase the yield of plant production. The intercropping allows to optimize the use of environmental resources, such as nutrients, water and solar radiation, since the plant species have different growth cycles. In this way, companion plants do not compete for nutrients, space, and light and do not have toxic (allelopathic) effects on each other.

The cultivation of these vegetables requires large amounts of nutrients, mainly due to their short period of development and growth (Silva et al., 2018). One of the possibilities of supplying this demand is through the use of green manure with mixtures of biomass from spontaneous species of the Caatinga biome, such as *Merremia aegyptia* and *Calotropis procera*. These species, according to Linhares et al. (2012), have "good fertilizer" qualities, as they consist of a good supply of nutrients, excellent biomass production and low C/N ratio, which provides the decomposition and faster release of nutrients to plants.

Regarding the amounts of green manures from mixtures of biomass of spontaneous species of the Caatinga biome together with the population densities of horticultural species in intercropped systems of tuberous and broadleaves, it has rarely been studied. Oliveira et al. (2017) evaluating the agro-economic efficiency of agrosystems from arugula (A) and lettuce (L) crops in intercropping with carrot (C) in different amounts of *Calotropis procera* biomass incorporated into the soil and in different proportions of population densities between component crops, obtained greater productive and economic efficiency when incorporated to the soil the amount of 25 t ha^{-1} of *Calotropis procera* biomass at the population densities of 50% A-50% C-50% L of those recommended in single cultivation.

As can be seen, the intercropped systems of beet and lettuce as a function of *M. aegyptia* and *C. procera* mixtures biomass amounts in different population densities of the component crops still lack scientific information about their productive and economic efficiency. Therefore, this work aimed to evaluate the production and agro-economic benefits of beet-lettuce intercrop under different *Merremia aegyptia* and *Calotropis procera* biomass equitative amounts at diverse lettuce population densities in two cropping years.

2. Methodology

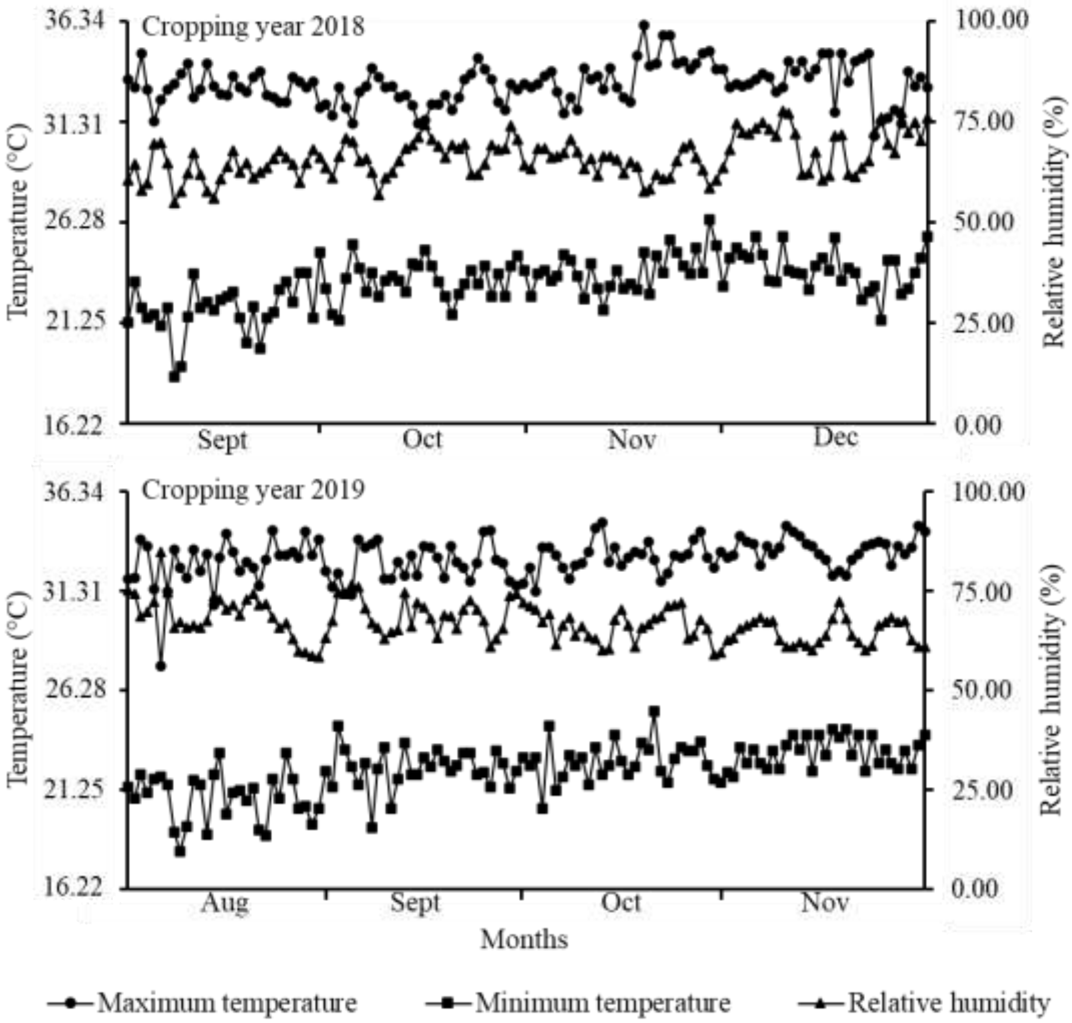
The methodology for preparing and conducting the field experiments of the beet intercropping with lettuce and of the use of experimental design in the execution of these experiments, as well as in the use of materials for conducting the field research, followed methodologies developed by Silva et al., 2018; Federer, 1993; Waddington et al., 1990.

2.1 Site description

Field experiments were conducted in different experimental areas from September to December 2018 and from August to November 2019 at experimental farm Rafael Fernandes, located in the Lagoinha district, 20 km from the municipality of Mossoró-RN, Brazil. The region's climate, according to the Köppen classification, is BShw, semi-arid, dry and hot, with a dry period from June to January and a rainy period from February to May (Oliveira et al., 2012). During the experimental periods, precipitation was 0.4 and 4.4 mm in the two years of cultivation; the average temperature and the relative humidity of the air were 27.8 ° C and 66.2%; respectively, for 2018 and 27.1 ° C and 67.1%, respectively, for 2019.

Figure 1 shows the daily values of minimum and maximum temperatures and relative humidity for each year of the beet cultivation in intercropping with lettuce.

Figure 1. Climatic data provided by National Meteorological Institute during the experimental period of the 2018 and 2019 cropping years.



Source: Authors.

The soils in the experimental areas were classified as typical Argisol Red Dystrophic (Rêgo et al., 2016). Before the installation of the experiments, soil samples were taken at a depth of 0-20 cm, air-dried and sieved to pass through a 2 mm sieve. Subsequently, the samples were analyzed at the Soil Fertility and Chemistry Laboratory of the Federal Rural University of the Semi-Arid (UFERSA), obtaining the following results (Table 1).

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Table 1. Chemical analyses of the soils before the incorporation of the biomass of spontaneous species *M. aegyptia* and *C. procera*, in the first (Soil 1) and in the second cropping year (Soil 2) in the experimental areas.

Prior to incorporation of the spontaneous species														
Soils of cropping areas	**N g kg^{-1}**	**pH (water)**	**EC ds m^{-1}**	**OM g kg^{-1}**	**P**	**K^{+}**	**Na^{+}**	**Ca^{2+}**	**Mg^{2+}**	**Cu**	**Fe**	**Mn**	**Zn**
					mg dm^{-3}			**cmol$_c$ dm^{-3}**		**mg dm^{-3}**			
Soil 1	0.35	8.10	0.24	4.97	22.8	64.7	32.7	3.28	0.78	0.10	1.91	11.67	2.63
Soil 2	0.28	7.10	0.10	5.27	22.0	69.5	26.7	2.70	0.50	0.24	2.10	12.17	5.27

N: Nitrogen; pH: Hydrogenionic potential; EC: Electrical conductivity; OM: Organic matter; P: Phosphorus; K^{+}: Potassium; Na^{+}: Sodium; Ca^{2+}: Calcium; Mg^{2+}: Magnesium; Cu: Copper; Fe: Iron; Mn: Manganese; Zn: Zinc. Source: Authors

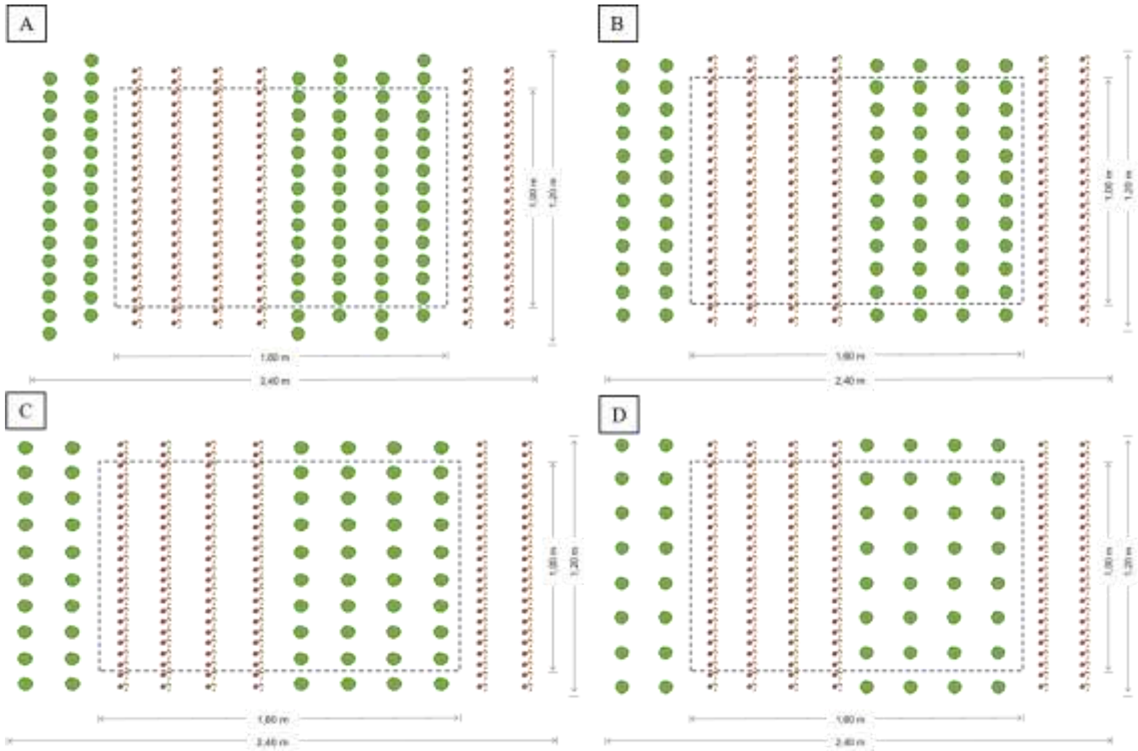
In Soil 1, the contents of the nutrients N, Na, Ca, and Mg showed higher values than that of Soil 2, while the content of Zn soil 2 was higher than that of soil 1 (Table 1).

2.2 Experimental design and treatments

The experimental design used in the experiments was 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 biomass of *M. aegyptia* and *C. procera* (20, 35, 50 and 65 t ha^{-1} on a dry basis), and the second factor by four population densities of lettuce plants (150, 200, 250, and 300 thousand plants ha^{-1}), corresponding to (60, 80, 100 and 120% of the recommended density for sole crop - RDSC of lettuce). The recommended population densities for single crops of beet and lettuce in the region are 500 and 250 thousand plants ha^{-1}, respectively (Silva et al., 2011; Paula et al., 2017). In intercropped system, the same population density as beet from single crop was used. In each block, single plots of beet and lettuce fertilized with optimized by the research equitable amounts of *M. aegyptia* and biomass were used to obtain the agronomic and economic indexes of the intercropped system.

The intercropped system was established in alternating bands of component crops in the proportion of 50% of the area occupied with beet and 50% with lettuce, where in each plot the alternating bands consisted of four rows, flanked by two rows of lettuce on one side and two rows of beets on the other side, used as borders (Figure 2). The total area of each plot was 2.88 m^{2} (2.40 x 1.20 m), with a useful area of 1.60 m^{2} (1.60 x 1.00 m). The harvest area was made up of the two central strips of plants, excluding the first and last plants of each row of strips used as borders.

Figure 2. Details of plots of beet intercropped with lettuce in a certain *M. aegyptia* and *C. procera* biomass amount in the lettuce population densities of 150, 200, 250 and 300 thousand plants, and of 500 thousand of beet plants per hectare.



Source: Authors.

Single crops of the vegetables had a total area of 1.44 m^2 (1.20 x 1.20 m) and a harvest area of 0.80 m^2 (0.80 x 1.00 m) for beet and 0.60 m^2 (0.80 x 0.80 m) for lettuce (Figures 3 and 4).

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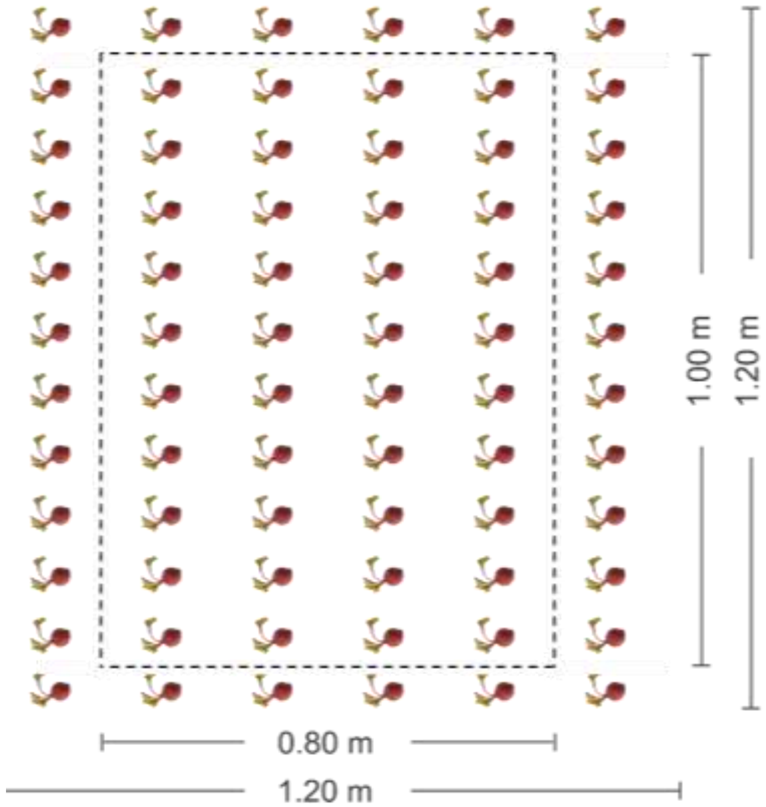
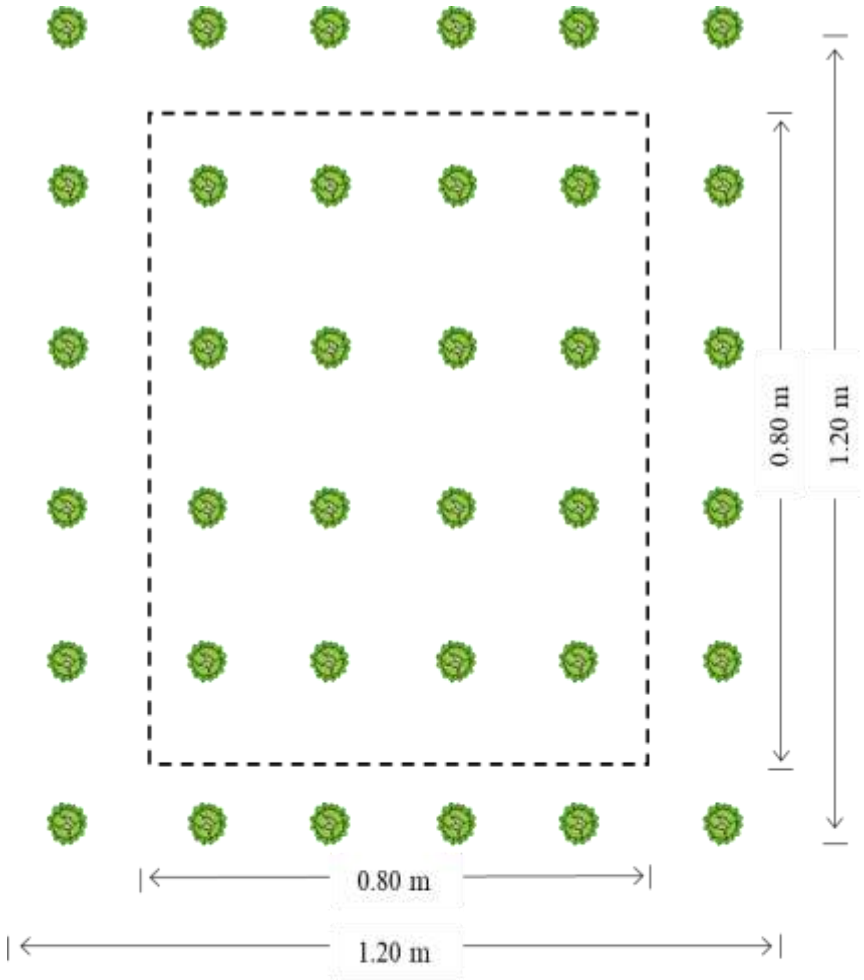
Figure 3. Detail of a plot of the single crop of beet in the density of 500 thousand plants per hectare.



Source: Authors.

Figure 4. Detail of a plot of the single crop of lettuce in the density of 250 thousand plants per hectare.



Source: Authors.

These single croppings are important in the evaluation of the agro-economic efficiency indexes of the intercropped systems.

The spacings of the lettuce and beet used in the intercropping and monocropping are shown in Table 2.

Table 2. Description of the population densities of beet and lettuce used in intercropping and monocropping, with their respective spacings.

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

Source: Authors.

This table shows the spacings between rows and between plants of beet and lettuce crops in intercropped system in all combinations of the production factors studied (amounts of green manures and lettuce population densities) as well as the spacings between rows and between plants of the crops in monocropping in the population density of each culture optimized in research carried out in the region, thus allowing the visualization of the sources of variation to be evaluated in this research.

The spacing of the beet used in the intercropped system was 0.20 x 0.05 m, with 80 plants per harvest area, corresponding to the population density of 500 thousand plants per hectare (Figure 2). In the single crop of this vegetable, the spacing used was 0.20 x 0.10 m, with 40 plants per harvest area, corresponding to the population density also of 500 thousand plants per hectare (Figure 3). The lettuce spacings in the intercropping were 0.20 x 0.08 m; 0.20 x 0.10 m; 0.20 x 0.125 m and 0.20 x 0.166 m, providing 24, 32, 40 and 48 plants per harvest area, respectively, corresponding to the population densities of 150, 200, 250 and 300 thousand plants per hectare (Figure 2). The spacing of lettuce in single crop was 0.20 x 0.20 m, with 16 plants per harvest area, corresponding to a population density of 250 thousand plants per hectare (Figure 4).

2.3 Crop management and practices

Before setting up 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 rotating harrow. Subsequently, pre-planting solarization was carried out with transparent plastic like Vulca Brilho Bril Flex (30 microns) for 30 days to combat phytopathogenic microorganisms in the soil.

The green manures *M. aegyptia* and *C. procera* were collected in rural areas located in the municipality of Mossoró-RN. Then, they were crushed in a conventional forage, obtaining fragmented particles around 2.0 to 3.0 cm, dehydrated in the sunlight for a period of three to five days until reaching a moisture content of 10%. Material samples were subjected to laboratory analysis resulting in the following results obtained in Table 3.

Table 3. Chemical analysis of macronutrients presents in the dry biomass of green manures *M. aegyptia* and *C. procera* in the first and second cropping year.

Green manures	**N**	**P**	**K**	**Mg**	**Ca**
		------------------------------------g kg^{-1} -----------------------------			
			Cropping year 2018		
M. aegyptia	16.60	2.79	37.80	7.07	19.35
C. procera	21.90	1.92	20.90	9.22	17.00
			Cropping year 2019		
M. aegyptia	15.30	4.00	25.70	7.03	9.30
C. procera	18.40	3.10	24.50	13.50	16.30

N: Nitrogen; P: Phosphorus; K: Potassium; Mg: Magnesium and Ca: Calcium; Mg. Source: Authors.

In these results, it can be observed the K content in the year 2018 was higher than that of the year 2019.

The beet cultivar 'Early Wonder' was sown on September 11, 2018 in the first year of cultivation and on August 27, 2019 in the second year of cultivation. Two lettuce cultivations were carried out in each agricultural year, with the production of seedlings of the lettuce cultivar 'Tainá' carried out by the company "Canto Verde", in a period of 20 days. After that, they were transplanted to the field in their first cultivation at the same day of beet planting, and in second cultivation on November 6, 2018 and October 21, 2019.

The beet was sown in the field in beds, in 3.0 cm deep pits, with two to three seeds per hole, while the lettuce was sown in 200-cell styrene trays with three seeds per cell and transplanted 20 days later in holes of 5.0 cm in depth in the beds, leaving after the thinning carried out at 7 days a seedling per hole. The beet thinning was carried out seven days after planting, leaving one plant per hole.

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). 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, when necessary, by means of manual harvesting of the plants. No pest and disease control methods were needed.

The beet harvests were carried out at 70 and 71 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.

2.4 Measurements

In the beet culture, the characteristics evaluated were plant height, number of leaves per plant, fresh and dry of shoots mass, dry mass of roots, total and commercial productivity of roots and classified productivity of roots, in great, extra AA, extra A, extra and scrap (Batista et al., 2016). In lettuce culture, plant height and diameter, number of leaves per plant, leaf productivity and dry mass of shoots were evaluated.

In the intercropped systems of beet and lettuce, the following agronomic and monetary indexes were evaluated.

The system productivity index (SPI) was expressed by the following formula (Pinto et al., 2012): SPI = $[(Y_b/Y_l) \times Y_{lb}] + Y_{bl}$, where Y_b represents the commercial productivity of beet roots and Y_l, lettuce productivity in single crop; Y_{lb} is the productivity of lettuce intercropped with beets; Y_{bl} is the commercial productivity of beet roots intercropped with lettuce. The advantage of SPI is that this index standardizes the productivity of the secondary crop (lettuce) according to the main crop (beet). The higher the index value, the more efficient the cultivation system is.

The equivalent land coefficient (LEC) was calculated according to the methodology used by Pinto et al. (2012): $LEC = LER_b \times LER_l$, where, LER_b and LER_l represent the partial land ratios of beet and lettuce, respectively. For the intercropped system, the minimum LEC is 0.25, that is, the intercropped system has a productive advantage when this index exceeds 0.25.

The monetary equivalence ratio (MER) was determined according to the methodology proposed by Afe & Atanda (2015): $MER = (GI_{bl} + GI_{lb})/GI_b$, where GI_{bl} is the gross income of beet intercropped with lettuce; GI_{lb} is the gross income of lettuce intercropped with beet; GI_b is the highest gross income of beet in single cropping, when compared to that of lettuce. This index measures the economic superiority, or not, of the intercropping over single cropping of the most economical culture. The higher the value of the index, the more profitable the cultivation system is.

2.5 Statistical analysis

The univariate analysis of variance for the randomized block design in a factorial scheme was used to evaluate the variables collected. A joint analysis was carried out for the two years of cultivation for the characteristics of the two cultures and the F test used to compare the averages between years of cultivation and cultivation systems, using the SISVAR software (Ferreira, 2011). For the agronomic and economic indices, due to the homogeneity of the variances between the years of cultivation, an average of the years of cultivation was made and a regression analysis was performed on these indices. The procedure for adjusting the regression curves was performed using the Table Curve software (Jandel Scientific, 1991) to estimate the behavior of each variable as a function of the equitable amounts of biomass of *M. aegyptia* and *C. procera* and the population densities of lettuce studied.

3. Results and Discussion

3.1 lettuce crop

No significant interaction was observed between the factors equitable amounts of green manures biomass, population densities of lettuce and cropping years in the agronomic variables: plant height and diameter, number of leaves per plant, productivity and dry mass of lettuce shoots intercropped with beet (Table 4).

Table 4. F values for plant height (PH), number of leaves per plant (NLP), plant diameter (PD), leaf productivity (LP) and dry mass of shoots (DMS) of lettuce intercropped with beet as a function of lettuce population densities and *M. aegypti*a and *C. procera* biomass amounts incorporated into the soil at two cropping years.

Sources of variation	PH	NLP	PD	LP		DMS
Blocks(Cropping years)	2.13^{ns}	0.88^{ns}	2.57^{ns}	2.90^{*}		0.70^{ns}
Cropping years (Y)	85.67^{**}	13.03^{**}	20.53^{**}	435.01^{**}		15.08^{**}
Amounts of *M. aegyptia* and *C. procera* biomass (A)	122.28^{**}	50.64^{**}	92.76^{**}	118.54^{**}		43.17^{**}
Population densities of lettuce (D)	0.91^{ns}	3.13^{*}	4.49^{**}	21.17^{**}		20.32^{**}
Y x A	0.51^{ns}	1.85^{ns}	1.83^{ns}	10.23^{**}		1.32^{ns}
Y x D	3.56^{*}	0.55^{ns}	1.67^{ns}	3.32^{*}		1.85^{ns}
A x D	1.82^{ns}	0.53^{ns}	1.03^{ns}	3.22^{**}		1.45^{ns}
Y x A x D	1.40^{ns}	0.71^{ns}	0.76^{ns}	1.93^{ns}		0.76^{ns}
Monocropping (M) x Intercropping (I)	11.42^{**}	11.60^{**}	18.81^{**}	181.17^{**}		84.43^{**}
Y x M vs I	0.74^{ns}	0.02^{ns}	1.26^{ns}	4.64^{*}		0.01^{ns}
CV (%)	7.62	11.19	7.78	17.95		22.75
Cropping years						
2018	13.20A	11.27A	18.44A			1.50A †
2019	11.70B	10.51B	17.36B			1.28B
Cropping systems				2018	2019	
Intercropping	12.38B	10.80B	17.77B	19.05aB	9,23bB	1.33B
Monocropping	13.55A	12.31A	19.98A	30.08aA	24,46bA	2.40A

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

In this Table, it is possible to observe the presence or not of interaction between the factors of production studied (amounts of green manures and population densities) in the characteristics of the lettuce, in the cropping years and systems used, thus allowing to register the behavior of this characteristics in intercropping and monocropping.

However, a response surface was adjusted to these variables, where the height and diameter of plants, number of leaves per plant, productivity and dry mass of shoots reached the maximum values of 14.45 and 21.11 cm; 13 leaves; 22.05 and 2.01 t ha^{-1} in the combinations of equitable amounts of biomass from green manures and lettuce population densities of 65 and 224 lettuce; 65 and 150; 65 and 150; 65 and 300, and 65 t ha^{-1} and 300 thousand plants per hectare, respectively (Figures 5A, 5B, 5C, 5D and 5E).

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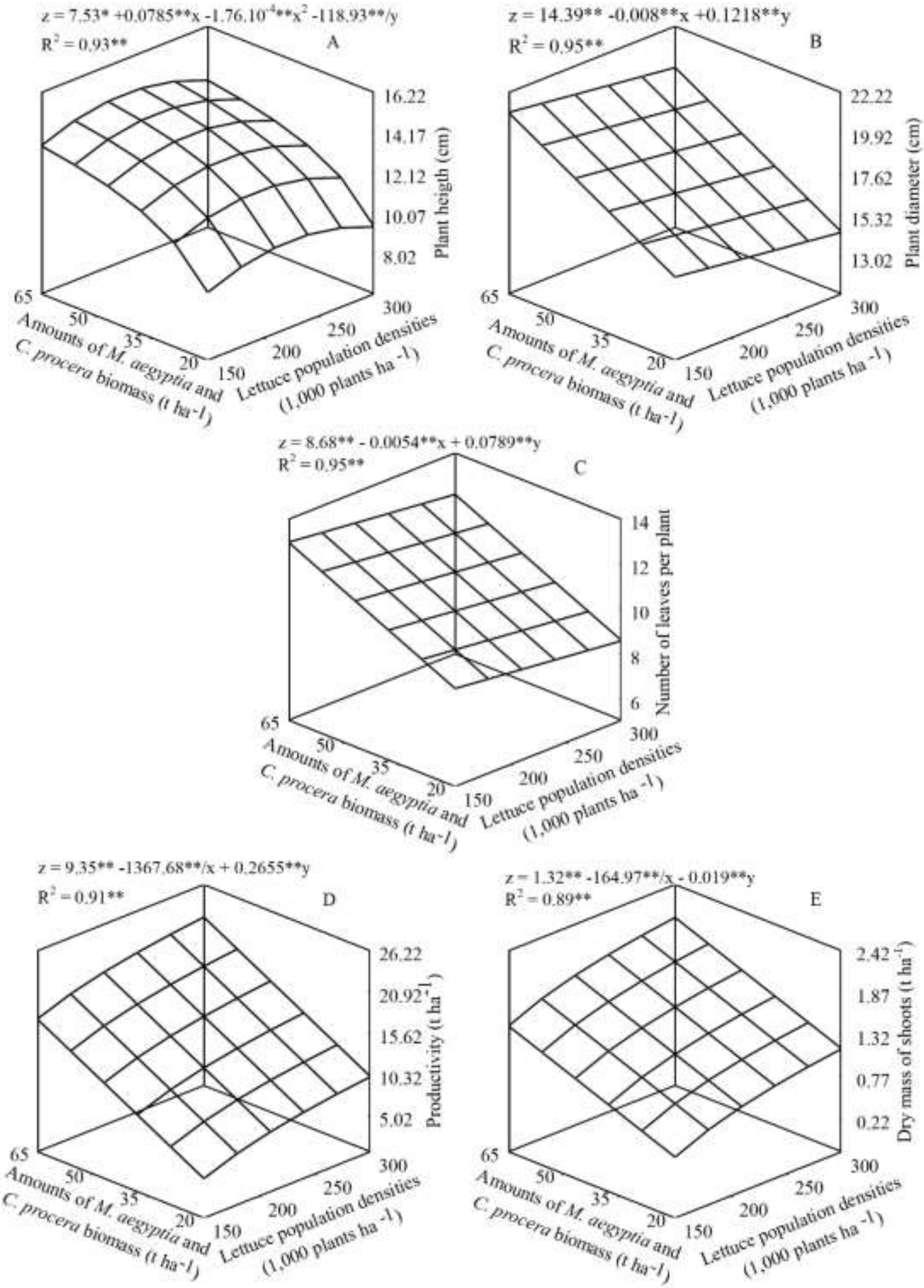
Figure 5. Plant height (A) and diameter (B), number of leaves per plant (C), productivity (D) dry mass of shoots (E) of lettuce in bicropping, intercropped with beet in different combinations of *M. aegyptia* and *C. procera* biomass equitable amounts incorporated into the soil and population densities of lettuce in the cropping years of 2018 and 2019.



Source: Authors

This Figure 5 shows us which combination of the biomass amount of the mixture of green manures with the population density of lettuce registered the maximum value of the lettuce variables, thus allowing register the impact of competition on the process of photosynthesis of this broadleaf crop, evidenced by their productivity, number of leaves per plant and production of dry mass of leaves.

An interaction between cropping systems and cropping years was recorded only in the lettuce leaf productivity (Table 4). Studying the cropping years within the cropping systems, it was observed that they differed, with the year 2018 standing out from the year 2019. On the other hand, analyzing the cropping systems within the cropping years, it was registered that the monocropping exceeded the intercropping in each year in this agronomic variable (Table 4).

For plant height and diameter, number of leaves per plant and dry mass of shoots, significant differences were registered between the cropping years and systems, with the year 2018 standing out from the year 2019 and the monocropping overcoming the intercropping in these variables (Table 4).

The definition of the fertilization and the number of plants per area is of fundamental importance to obtain gains in the production of intercropped systems when different species are planted together. It is known that higher doses of fertilization allow better development and growth of plants, and when they are associated with not so high population densities of one of the crops, the productivity of the system can be optimized, due to the better use by the intercropping system of the nutrients made available by the fertilization and the environmental resources involved, thus optimizing the system's production variables.

This phenomenon can be observed in the results obtained with the plant height, number of leaves per plant and plant diameter of lettuce, where the highest amount of the green manures interacting with a not so high population density of lettuce provided the greatest results of these variables. This means that in the intercropped system, lettuce made better use of the availability of nutrients and of environmental resources in a population density of 60% RDSC, thus minimizing interspecific competition and, mainly, the intraspecific of lettuce culture.

The results of the productivity and of dry mass of lettuce shoots can be attributed both to the content of nutrients present in the largest amount of the mixture, and to the higher population density of the lettuce that made better use of the environmental resources promoted by water, light and nutrients of the green manuring. These results corroborate with observations made by Filgueira (2013), when reporting that the efficiency of the use of organic fertilizer is related to the increase of the sprouting and production of green mass of the plants due to the increase in the availability of nutrients and, thus, favoring the properties physical and activities of soil organisms. Batista et al. (2016), studying the efficiency of the arugula and carrot intercropping in different populations, claim that the increase in the production of green mass of the arugula with the increase in the population density of leafy vegetable is due to the greater number of plants per area.

Regarding the results obtained in the cropping systems, lettuce had the highest production and of its components in the monocropping when compared to the intercropping. This result is due to the lower intraspecific competition of lettuce in the monocropping. It must be considered that the proximity of the crops in the intercropping predisposes to interspecific competition, that is, more 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 monocropping in relation to the intercropping in this study.

3.2 Beet crop

A significant triple interaction was observed between production factors, equitable amounts of the green manures biomass, population densities of lettuce and cropping years in agronomic variables above ground, plant height and dry mass of shoots (Table 5).

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Table 5. F values and mean values for plant height (PH), number of leaves per plant (NLP), dry mass of shoots (DMS), productivity of total (PTR) and commercial roots (PCR), productivity of large (PGL), extra AA(PEAAR), extra A(PEAR) and extra (PER) roots of beet intercropped with lettuce as a function of *M. aegyptia* and *C. procera* biomass amounts and lettuce population densities at two cropping years.

Sources of variation	PH	NLP	DMS	PTR	PCR	PGL	PEAAR	PEAR	PER
Blocks (Cropping years)	2.23*	1.28ns	2.53*	1.88ns	1.89ns	7.75**	1.21ns	2.66*	4.25**
Cropping years (Y)	20.81**	11.21**	59.47**	1.07ns	7.47**	4.57ns	2.21ns	0.23ns	1.30ns
Amounts of *M. aegyptia* and *C. procera* biomass (A)	13.57**	1.85ns	47.52**	104.13**	143.36**	77.48**	17.02**	13.92**	29.33**
Population densities of lettuce (D)	4.40**	3.71*	3.58*	18.39**	16.17**	7.78**	5.63**	0.98ns	3.76*
Y x A	1.24ns	0.09ns	1.67ns	4.34**	2.14ns	1.81ns	0.65ns	0.52ns	2.28ns
Y x D	2.78*	0.36ns	7.40**	1.51ns	4.82**	2.25ns	0.50ns	5.56**	16.04**
A x D	1.39ns	0.15ns	1.33ns	2.90**	1.90ns	0.59ns	0.81ns	2.69**	2.09*
Y x A x D	2.23*	0.37ns	3.92**	3.23**	5.19**	1.53ns	2.10*	1.24ns	0.76ns
Monocropping (M) x Intercropping (I)	0.04ns	1.28ns	54.61**	57.27**	68.49**	46.28**	2.75ns	5.71*	13.24**
Y x M vs I	3.94ns	2.80ns	0.35ns	2.90ns	1.91 ns	2.85ns	0.76ns	0.81ns	0.65ns
CV (%)	5.84	11.43	13.99	10.47	10.73	28.97	27.95	32.28	33.52
Cropping years									
2018	44.12A	7.32B	2.84A	26.63A	24.63B	10.89A	6.43A	3.69A	4.19A
2019	42.15B	7.82A	2.35B	27.13A	25.90A	11.49A	6.90A	3.59A	3.93A
Cropping systems									
Intercropping	43.15A	7.55A	2.54B	26.42B	24.79B	10.45B	6.60A	3.57B	4.17A†
Monocropping	42.96A	7.90A	3.51A	34.18A	32.96A	18.28A	7.73A	4.60A	2.36B

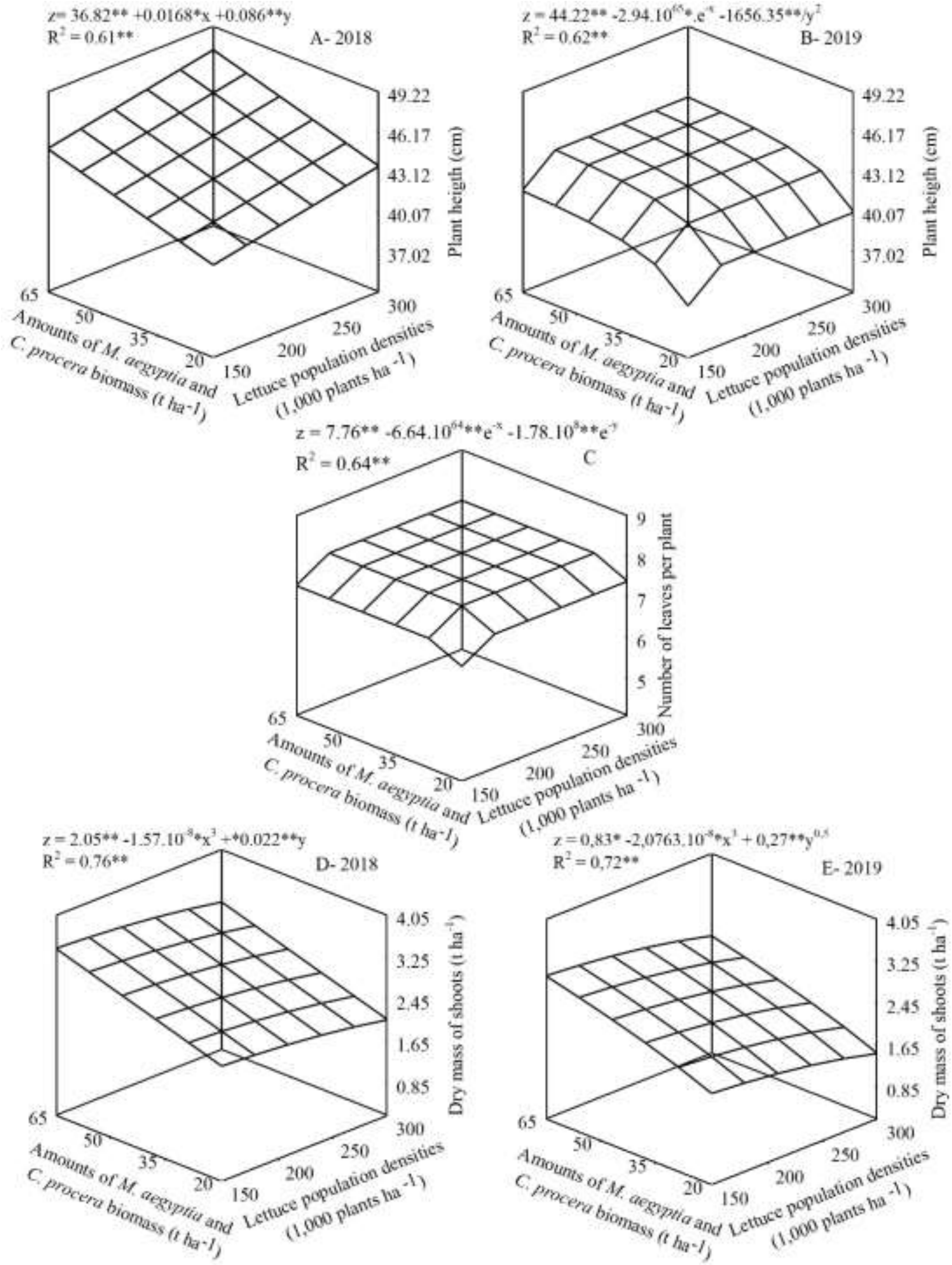
** = P < 0.01; * = P < 0.05; ns = P > 0.05. † Means followed by different lowercase letters in the column differ statistically from each other by the F test at the 5% probability level. Source: Authors.

In this Table, it is possible to observe the presence or not of interaction between the factors of production studied (amounts of green manures and population densities) in the characteristics of the beet, in the cropping years and systems used, thus allowing to register the behavior of this characteristics in intercropping and monocropping.

A response surface was adjusted to this interaction, where the maximum values of the above-ground agronomic variables were 47.45 and 43.83 cm and 3.43 and 2.94 t ha^{-1}, in the combinations of equitable amounts of *M. aegyptia* and *C.*

procera biomass and population densities of 65 and 300 and 65 t ha^{-1} and 253 thousand plants per hectare at the plant height and 65 t ha^{-1} and 150 thousand plants per hectare in the dry mass of beet shoots, respectively, in the cropping years of 2018 and 2019 (Figures 6A, 6B, 6D and 6E).

Figure 6. Plant height (A and B), number of leaves per plant (C) and dry mass of shoots (D and E) of beet intercropped with lettuce in bicropping as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and population densities of lettuce in the cropping years of 2018 and 2019.



Source: Authors.

In other words, this Figure 6 shows us which combination of the biomass amount of the mixture of green manures with the population density of lettuce registered the maximum value of the beet variables evaluated above the ground, thus allowing register the impact of competition on the process of photosynthesis, evidenced by the biomass production of beet shoots in intercropping with the lettuce.

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

For the dry mass of the shoots, it can be inferred that the greater shading imposed by the increase in the number of lettuce plants in the area, had a negative impact on photosynthesis and, consequently, allowed the dry mass of the beet shoots to reach the maximum in a population low lettuce. According to Paciullo et al. (2011), affirm that the shading reduces the production of dry mass, for causing the deficiency in the translocation of photoassimilates; therefore, the maximum production of dry mass was reached in low lettuce densities. In intercropped systems, where the nutritional conditions of the soil are suitable for cultivation, competition for light can be more intense, and the use of higher densities can increase competition for this natural resource (Gebru, 2015, Nascimento et al., 2018).

No significant interaction was observed for any of the production factors previously mentioned in the agronomic variable number of leaves per beet plant intercropped with lettuce in a bicropping (Table 5). However, a response surface was adjusted to this variable, where the maximum value of 7.8 leaves per plant was achieved by combining of green manures biomass amount and population densities of 65 t ha^{-1} and 280 thousand plants per hectare (Figure 6C). As the nutritional conditions of the soil were adequate to the intercropped system, the number of leaves per plant of beet was obtained in a high density of lettuce. Lima et al. (2013), state that as the population density increases, within certain limits, there is an increase in the number of leaves per plant. This is only achieved when an ideal plant density is used, which is sufficient to achieve the optimum leaf area index, in order to intercept the maximum amount of solar radiation useful for photosynthesis and at the same time maximize the fraction of the allocated dry mass (Kaggwa-Asiimwe et al. 2013).

No significant interaction between cropping systems and cropping years was recorded in the variables evaluated in the above-ground beet (Table 5). The monocropping surpassed the intercropping in the dry mass of shoots, while that, in the plant height and in the number of leaves per plant, it was similar to intercropped system of beet and lettuce (Table 5). In relation to the cropping years, the year of 2018 surpassed that of 2019 in terms of plant height and shoot dry mass, while in the number of leaves per plant the behavior was reversed.

For the variables below ground: total and commercial root productivity and productivity of beet roots extra AA intercropped with lettuce in bicropping, significant triple interaction between production factors, equitable amounts of green manures biomass, population densities of lettuce and cropping years were also recorded (Table 5).

A response surface was adjusted to this interaction, where the maximum values of total and commercial root productivities were 33.50 and 33.93 and 33.34 and 32.77 in the years 2018 and 2019, respectively, in the combinations of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass with 300 thousand lettuce plants per hectare (Figures 7A, 7B, 7C and 7D) and the productivity of extra AA roots were 8.12 and 8.38 t ha^{-1} in these two years in the combinations of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass with 203 and 300 thousand lettuce plants per hectare (Figures 8A and 8B).

Figure 7. Total (A and B) and commercial productivity of roots (C and D) of beet intercropped with lettuce in bicropping as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and population densities of lettuce in the cropping years of 2018 and 2019.

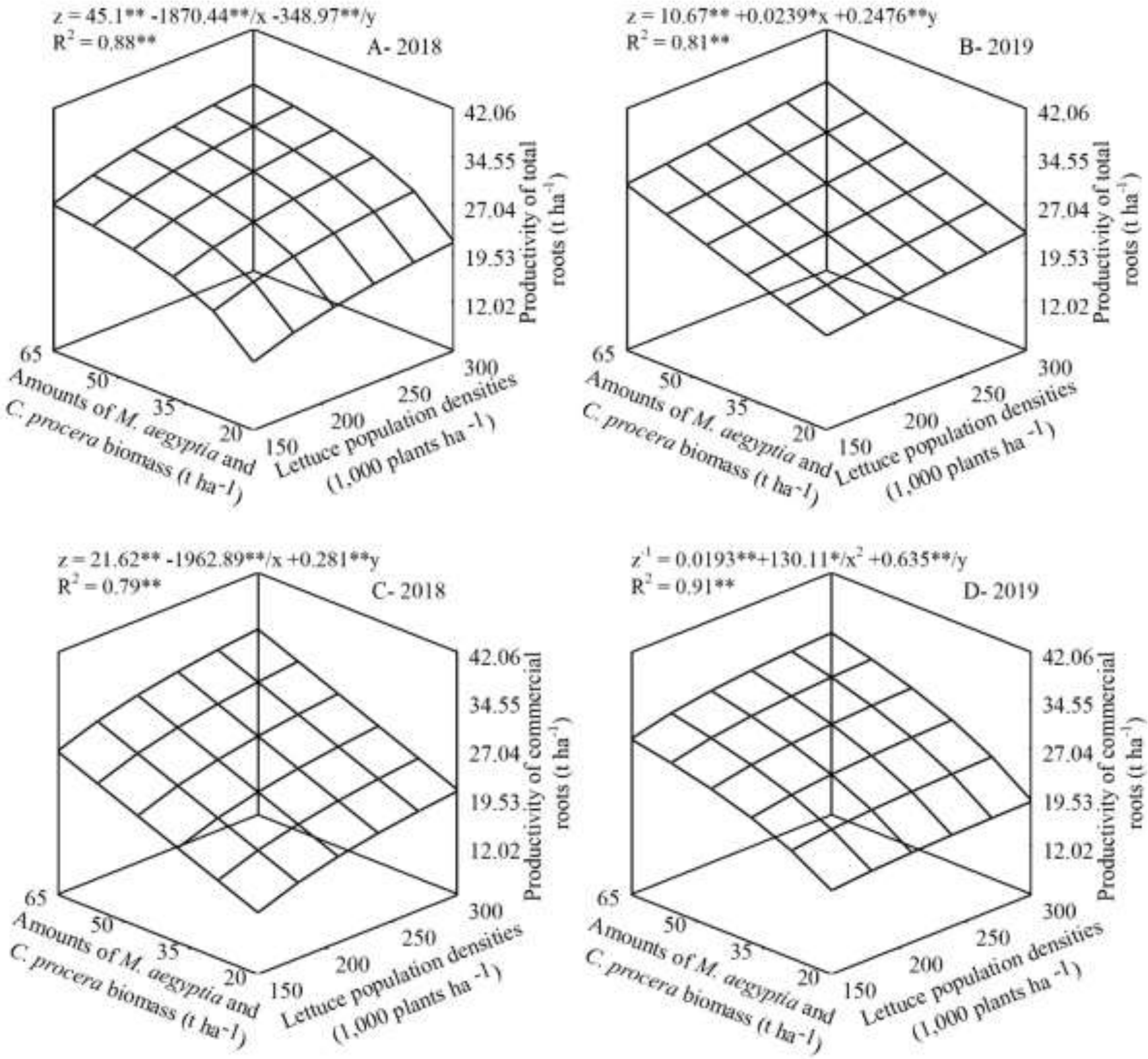


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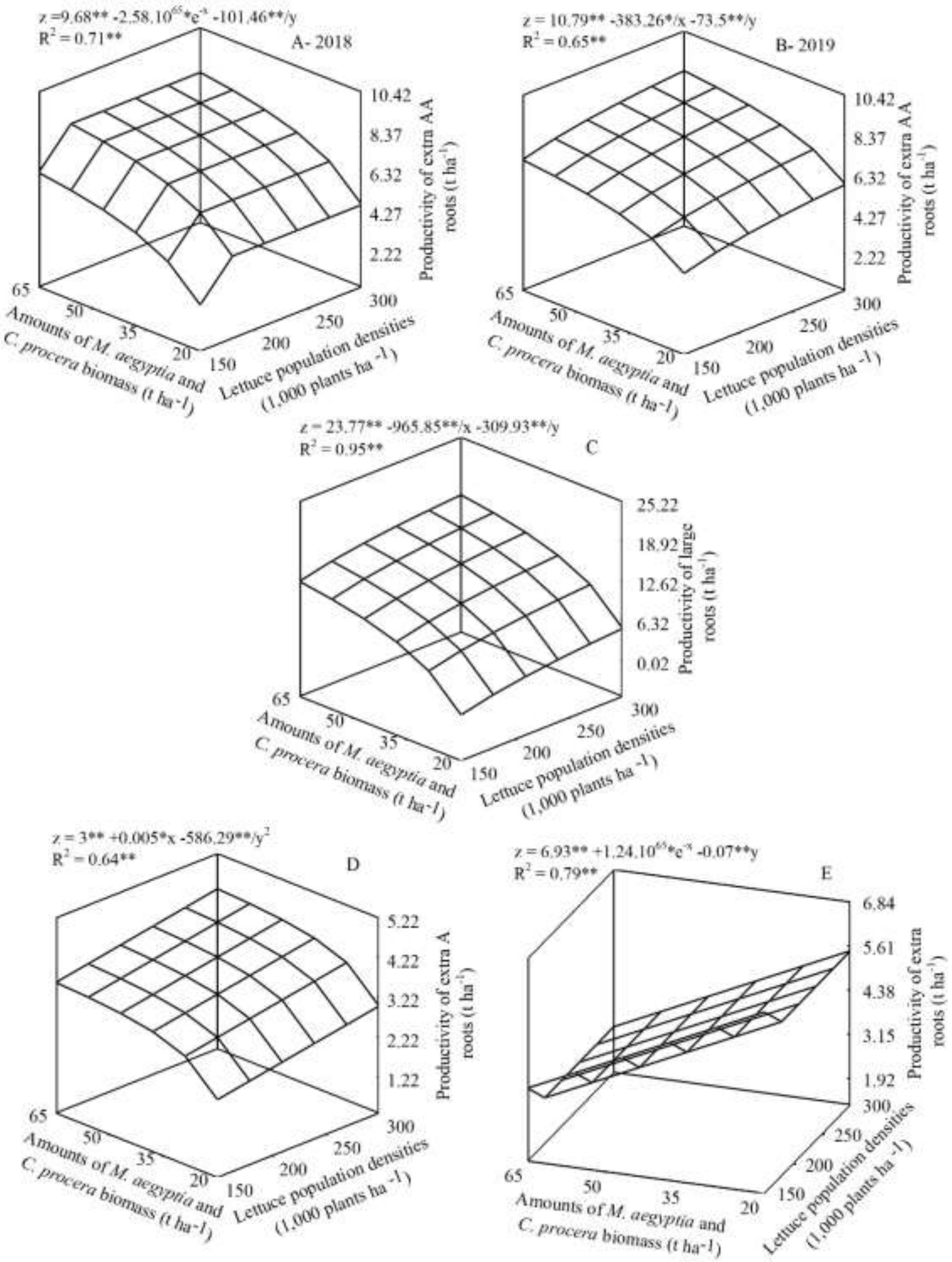
Figure 8. Productivity of roots extra AA (A and B), large (C), extra A (D) and extra (E) of beet intercropped with lettuce in bicropping as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and population densities of lettuce in the cropping years of 2018 and 2019.



Source: Authors.

The Figures 7 and 8 show us which combination of the biomass amount of the mixture of green manures with the population density of lettuce provides the maximum value of the beet variables evaluated below the ground, thus allowing to register if there is complementarity between these two vegetables in the commercial and classified productivity of beet roots.

In the productivity of large beet roots, extra A and extra, no significant triple interaction between production factors, equitable amounts of the green manures biomass, lettuce population densities and cropping years were not registered (Table 5). A response surface was adjusted to the variables, obtaining the maximum values of large and extra roots A of 15.78 and 4.36 t ha^{-1} in the equitable amount of the green manures of 65 t ha^{-1} and in the density of 300 thousand plants of lettuce per hectare (Figures 8C and 8D), while the productivity of extra roots, the maximum value reached was 6.42 t ha^{-1} in the equitable amount of the green manures of 20 t ha^{-1} and in the density of 150 thousand lettuce plants per hectare (Figure 8E).

The increase in productivity with the equitable amounts of green fertilizers is due, in part, to the greater availability of nutrients, mainly N, P and K released by the fertilizers (Batista et al., 2016), as well as by the improvement in chemical and physical-chemical characteristics of the soil obtained with the addition of these increasing amounts of green manure. According to Fontanétti et al. (2006), the absorption of nutrients resulting from the mineralization of green manure by vegetables depends, to a great extent, on the synchrony between the decomposition and mineralization of plant residues and the time of greatest demand for the crop. This decomposition is controlled by soil organisms, by environmental conditions and by the nature or chemical composition of the decomposing material (Xu & Hirata, 2005). On the other hand, this increase is also due to the increase in population density up to a certain density, where there is a decrease in productivity (large roots), due to the excessive competition that is established between the plants of the cultivation system. The interaction between plants in a community induces morphological and physiological changes, which are important for determining the productive potential of crops. Responses to plant density include changes in community architecture, growth, development and absorption and partition of assimilated plants (Adams et al., 2019).

No significant interaction between crop systems and years of cultivation was also recorded in the variables evaluated in the beet below ground (Table 5). The monocropping system surpassed the intercropping in total, commercial, large and extra root productivities. In extra root productivity, the intercropping surpassed the monocropping. There were no significant differences between cropping systems in extra AA root yields. In relation to the cropping years, the year of 2019 surpassed that of 2018 in the productivity of commercial roots, while in the other productivities evaluated, no significant difference was observed between the cropping years.

3.3 Agro-economic indices

Significant interaction between the factors-treatments equitable amounts of biomass of *M. aegyptia* and *C. procera* and population densities of lettuce was observed only in the agro-economic indices, equivalent coefficient of land (LEC) and monetary equivalence ratio (MER) evaluated in the intercropped systems (Table 6).

Table 6. F values for system productive index (SPI), land equivalent coefficient (LEC) and monetary equivalent ratio (MER) of beet intercropped with lettuce as a function of different equitable amounts of *M. aegyptia* and *C. procera* biomass and population densities of lettuce.

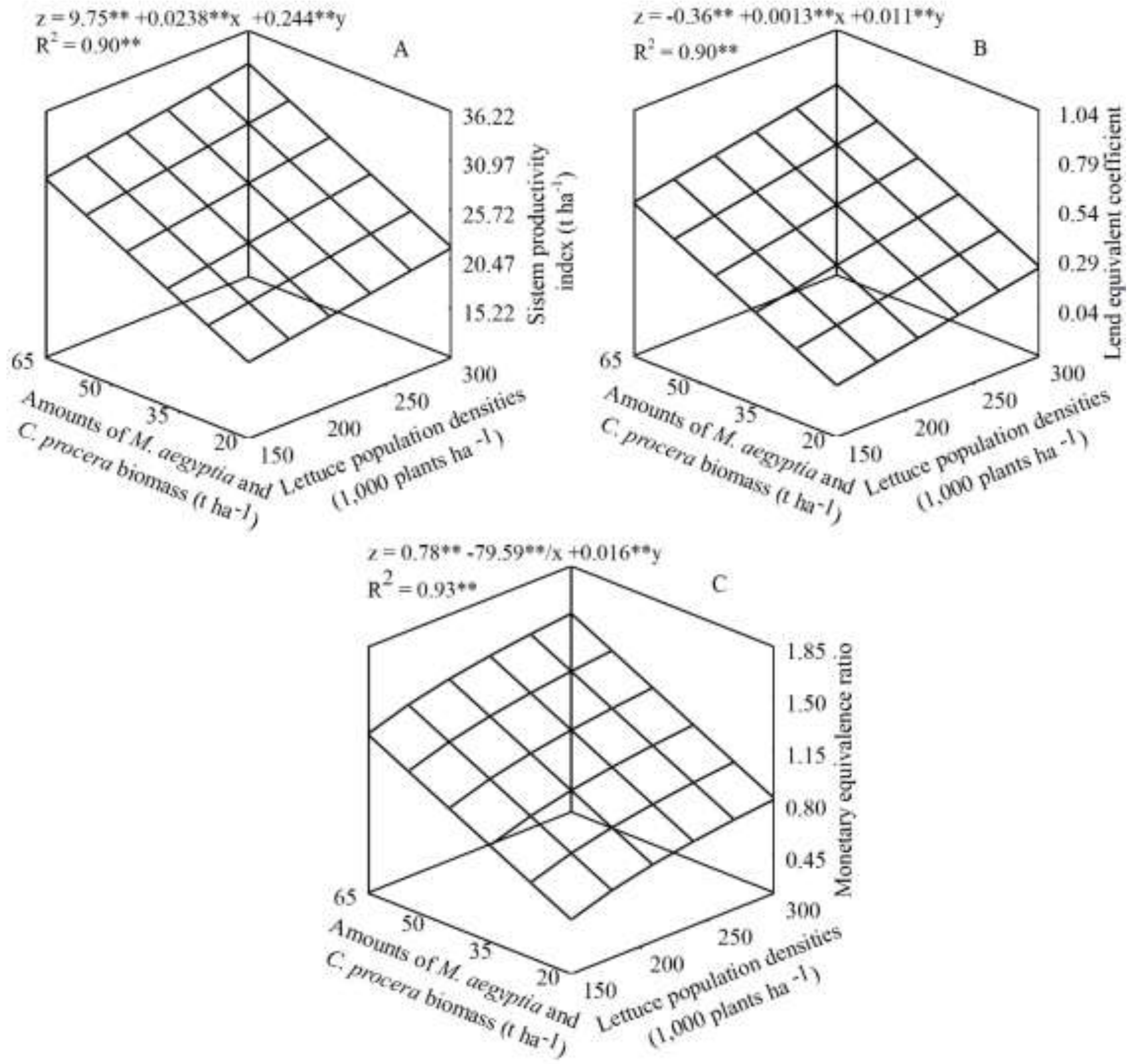
Sources of variation	SPI	LEC	MER
Blocks	2.63^{ns}	1.68^{ns}	0.20^{ns}
Amounts of *M. aegyptia* and *C. procera* biomass (A)	116.78^{**}	195.47^{**}	229.80^{**}
Population densities of lettuce (D)	13.17^{**}	35.98^{**}	38.05^{**}
A x D	1.55^{ns}	5.26^{**}	4.54^{**}
CV (%)	7.09	15.48	7.51

** = P < 0.01; ns = P > 0.05. Source: Authors.

In this Table, it is possible to observe the presence or not of interaction between the factors of production studied (amounts of green manures and population densities) in the agro-economic indices of the intercropping systems, thus allowing register their technological viability in environment semi-arid.

However, a response surface was adjusted to the system's productivity index (SPI), the equivalent land coefficient (LEC) and the monetary equivalence ratio (MER), where they reached the maximum values of 32.75 t ha 1; 0.75 and 1.55 in the combination of equitable amounts of green manures biomass and population densities of 65 t ha^{-1} and 300 thousand plants per hectare, respectively (Figure 8). These results disagree with those obtained by Chaves et al. (2020), when intercropped beet with different population densities of cowpea in the same region of this research and obtained values of SPI = 29.23 t ha^{-1}, LEC = 0.59 and MER = 1.11, in population densities of cowpea of 200, 191 and 200 thousand cowpea plants per hectare. These differences in results are due to the use of the secondary culture in the intercropping system.

Figure 9. System productivity index (A), land equivalent coefficient (B) and monetary equivalence ratio (C) of beet intercropped with lettuce in bicropping as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and population densities of lettuce.



Source: Authors.

The Figure 9 shows us which combination of the biomass amount of the mixture of green manures with the population density of lettuce registered the maximum value of agro-economic indices in the beet and lettuce intercropped systems, thus allowing register if there is agro-economic viability in strip-intercroppings with these vegetables.

The values obtained in the research under analysis are indicative of the superiority of the intercropped system in relation to monocropping (Pinto et al., 2012; Afe & Atanda, 2015). These results indicate that in the intercropped system there was no negative effect of the high population density of the secondary culture in the competition for sunlight. It is known that the plant population in the intercropped system depends on the type and growth habit of crops, soil fertility, precipitation and other growth requirements (Gebru, 2015).

Regarding the agro-economic indices, SPI, LEC and MER as a function of the equitable amounts of biomass of *M. aegyptia* and *C. procera* incorporated in the soil, it can be seen that their optimized values of 32.24 t ha^{-1}; 0.86 and 1.50 were due in part to the incorporation of the mixture of green manures that contributed efficiently to the supply of nutrients. It is known, however, that green manures can provide nutrient cycling in the soil, bringing nutrients that are in greater depth to the surface, in order to meet demand (Tivelli et al., 2010).

Therefore, it can be registered that the highest values of LEC and MER were obtained in the combination 65 t ha^{-1} of the mixture of green manures with 300 thousand plants of lettuce per hectare, showing that the system intercropped in this combination is the most efficient agronomically and monetarily. When the intercropped system has a LEC much higher than 0.25 (Pinto et al., 2012) and a MER much greater than 1.0, this intercropped system is considered highly productive or profitable in relation to the monocropping of the component crops involved in the system, thus showing, complementary nature of these cultures.

We can thus affirm that the use of biomass mixtures of *M. aegyptia* and *C. procera* from the Caatinga biome proves to be a viable technology for producers who practice the cultivation of beet and lettuce in intercropped systems in a semiarid environment. With this cultivation practice, vegetable producers in the semi-arid region aim to optimize the planted area, increase the biodiversity of the soil microbiota, properly manage pests and diseases, with the objective of obtaining high productivity and intercropped systems with high economic viability.

4. Conclusion

The greatest agro-economic advantages of the beet intercropping with lettuce were achieved with a system productivity index (SPI) of 32.97 t ha^{-1}, land equivalent coefficient (LEC) of 0.87 and a monetary equivalence ratio (MER) of 1.55, respectively, in the combination of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass with a lettuce population density of 300 thousand plants per hectare. The maximum production of commercial beet roots in a system intercropped with lettuce was obtained with a productivity of 33.77 t ha^{-1} in the amount of 65 t ha^{-1} of *M. aegyptia* and *C. procera* biomass incorporated in the soil and in the density lettuce population of 300 thousand plants per hectare, while the maximum lettuce leaf production was achieved with a productivity of 24.40 t ha^{-1} in the same combination of green manure amounts and lettuce population densities. The maximum productivity of commercial beet roots of the large and extra AA types were obtained in the combinations of amounts of 65 and 35 t ha^{-1} of *M. aegyptia* and *C. procera* biomass and of population densities of 250 and 200 thousand plants per hectare, and the type A and extra, reached in the amount of biomass of 20 t ha^{-1} and in the density of 150 thousand lettuce plants per hectare. The use of biomass mixtures of *M. aegyptia* and *C. procera*, from the Caatinga biome, proved to be a viable technology for producers who practice the cultivation of beet with lettuce in intercropped systems in a semiarid environment. Given the search for high quality vegetable products from intercropping systems, there is a need for research on factors or treatments that evaluate genotypes suitable for the intercropping, sowing time, fertilization, planting spatial arrangement, population densities of the crops, methods of attributing of intercropping's advantages over monocropping and on the vegetable production systems in the different ecosystems where they are implemented.

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