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Production and benefits in carrot and vegetable cowpea associations under green manuring and spatial arrangements[1]

Produção e benefícios em associações de cenoura e feijão-caupi sob adubação verde e arranjos espaciais

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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, is the choice of many vegetable producers. To meet the demands of these producers, experiments were conducted under field conditions in a semi-arid environment to evaluate the production and agro-economic benefits of carrot x vegetable cowpea associations as a function of green manuring with biomass of *Merremia aegyptia* L., a spontaneous species from the Caatinga biome, in different spatial arrangements at two cropping years. The experimental design was a randomized complete block design with treatments arranged in a 4 x 3 factorial scheme, with four replications. The first studied factor was the amounts of *M. aegyptia* biomass (20, 35, 50, and 65 t ha^{-1} on a dry basis), while the second factor was the spatial planting arrangements (2:2, 3:3, and 4:4), corresponding to rows of carrot alternated with rows of vegetable cowpea. The production optimization of the carrot and cowpea cultures was achieved with the incorporation of the *M. aegyptia* biomass amounts of 32.69 and 50.17 t ha^{-1}, respectively, and agro-economic optimization of the entire intercropping system was obtained at a biomass amount of 34.66 t ha^{-1}. The spatial planting arrangement of 2:2 resulted in the greatest agro-economic efficiency of the crop association.

Key words: *Daucus carota*. *Vigna unguiculata*. Crop association. Agro-economic efficiency.

RESUMO - O uso de um sistema de cultivo que ofereça aos produtores melhor uso da terra, maior produtividade por unidade de área, maior diversificação na produção e, consequentemente, vantagens agroeconômicas, é a escolha de muitos produtores de hortaliças. Para atender a demanda desses produtores, experimentos de campo foram conduzidos em ambiente semiárido para avaliar a produção e os benefícios agroeconômicos de associações de cenoura e feijão-caupi em função da adubação verde com biomassa de *Merremia aegyptia* L., espécie espontânea do bioma Caatinga, em diferentes arranjos espaciais e épocas de cultivo. O delineamento experimental foi em blocos casualizados, com os tratamentos arranjados em esquema fatorial 4 x 3, com quatro repetições. O primeiro fator consistiu de quantidades de biomassa de *M. aegyptia* (20, 35, 50 e 65 t ha^{-1} em base seca), enquanto o segundo fator de arranjos espaciais de plantio (2:2, 3:3 e 4:4), de fileiras de cenoura alternadas com fileiras de feijão-caupi. A otimização da produção das culturas de cenoura e feijão-caupi foi alcançada com as quantidades de biomassa de *M. aegyptia* de 32,69 e 50,17 t ha^{-1}, respectivamente, e a otimização agroeconômica de todo o sistema de consorciação foi obtida com uma quantidade de biomassa de 34,66 t ha^{-1}. O arranjo espacial de 2:2 resultou na maior eficiência agroeconômica da associação de culturas.

Palavras-chave: *Daucus carota*. *Vigna unguiculata*. Cultivo consorciado. Eficiência agroeconômica.

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INTRODUCTION

In recent years, there has been a growing consumption of vegetable crops due to increased consumer awareness. In addition, some producers have been using cropping systems to maximize the production of crops in a sustainable way (DAMASCENO *et al*., 2016). Against this background, the intercropping system can provide higher crop production and promote a better ecosystem balance.

For producers, the use of intercropping systems results in better land use and higher productivity per unit of cultivated area, which allows a greater production diversity and, consequently, a better economic balance between production costs and net producer income (RIBEIRO *et al*., 2018). However, the efficiency and advantages of this cultivation system depend on several production factors (SILVA *et al*., 2017), including green manuring and spatial arrangements (FAVACHO *et al*., 2017).

Green manuring incorporates plant biomass, produced in the place of origin or not, to increase soil organic matter and nutrient levels, as well as improving its structure, aeration and water storage capacity in the soil, thus contributing to physical, chemical and biological properties of the soil. The choice of plants to meet these requirements depends on the potential of phytomass production and the capacity of nutrient absorption and accumulation.

In this sense, in Brazil, the use of spontaneous species of the Caatinga biome as green manure is an important option to improve the balance between increasing crop productivity and environmental exploitation (BEZERRA NETO *et al*., 2014), making it a viable alternative for vegetable producers working on a family farming basis.

Another factor of fundamental importance that can influence the productivity of the plants involved in intercropping is the spatial planting arrangement. When adequately applied, spatial planting may contribute to increased crop yields in mixed-species cultivation compared to monoculture systems (FAVACHO *et al*., 2017).

Thus, this work aimed to evaluate the production and benefits of carrot x vegetable cowpea intercrops as a function of green manuring with different amounts of *Merremia aegyptia* biomass incorporated into the soil in different spatial arrangements at two cropping years.

MATERIALS AND METHODS

Two experiments were conducted in different experimental areas from Jul. to Oct. 2017 and 2018 at the Rafael Fernandes Experimental Farm, Lagoinha District, 20 km from the Mossoró-RN municipality, Brazil (5º11’31” S and 37º20’40” W, 18 m above sea level). The climate of the region is semiarid and, based on Köppen’s climate classification, type “BShw”, namely dry and very hot. There are two distinctive seasons, including the dry season from Jun. to Jan. and the rainy season from Feb. to May (OLIVEIRA *et al*., 2012). The soil of the experimental area was classified as a typical Dystrophic Red Argisol (UNITED STATES DEPARTMENT OF AGRICULTURE, 1999). During the experimental period, rainfall was 0 mm in the two cropping years; average air temperature and the relative air humidity values were 27.3 °C and 62% for 2017 and 27.2 °C and 65% for 2018, respectively.

Prior to the establishment of the experiments, soil samples were taken from the 0-20-cm layer, air-dried, and sieved through a 2-mm mesh. Subsequently, the samples were processed and analyzed in the Laboratory of Soil Fertility and Chemistry of the Universidade Federal Rural do Semi-Árido (UFERSA), obtaining the following results: pH (in water) = 8.20, electric conductivity (EC) = 1.77 dS m^{-1}, organic matter (OM) = 3.64 g kg^{-1}, N = 0.51 g kg^{-1}, P = 10.30 mg dm^{-3}, K^+ = 57.20 mg dm^{-3}, Na^+ = 11.60, mg dm^{-3}, Mg^{2+} = 0.60 $cmol_c$ dm^{-3}, Ca^{2+} = 2.05 $cmol_c$ dm^{-3}, Cu = 0.19 $cmol_c$ dm^{-3}, Fe = 2.03 $cmol_c$ dm^{-3}, Mn = 10.43 $cmol_c$ dm^{-3}, and Zn = 6.21 $cmol_c$ dm^{-3}, for the first experimental area. For the second area, it was obtained the following results: pH = 8.10, CE = 0.24 dS m^{-1}, 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^+ = 13.70 mg dm^{-3}, Mg^{2+} = 0.78 $cmol_c$ dm^{-3}, Ca^{2+} = 3.28 $cmol_c$ 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}.

The experimental design was a randomized complete block with treatments arranged in a 4 x 3 factorial scheme, with four replications. The first factor was constituted by amounts of dry biomass of *M. aegyptia* incorporated into the soil (20, 35, 50, and 65 t ha^{-1}), and the second factor consisted of the spatial arrangements of the component cultures (2:2, 3:3, and 4:4), formed of rows of carrot and vegetable cowpea.

The intercropped cultivation of the crops was established in alternating rows according to the spatial arrangement between the carrot and vegetable cowpea, in the proportion of 50% of the area for the carrot and 50% of the area for the vegetable cowpea (FAVACHO *et al*., 2017). The total area of the plot in the 2: 2 arrangement was 2.40 m² (2.00 x 1.20 m), formed by double rows of carrot alternated with double rows of vegetable cowpea, flanked by two rows-border each one of the crops, with a harvest area of 1.00 m² (1.00 m x 1.00 m), containing 50 carrot plants in the 0.25 x 0.04 m spacing with 25 plants per linear meter, and 20 cowpea plants in the 0.25 x 0.25 m spacing with 10 plants per linear meter. The 3: 3

arrangement consisted of triple rows of carrot alternating with triple rows of vegetable cowpea, flanked by the same border rows as the 2: 2 arrangement. The total area of the plot was 3.00 m² (2.50 x 1.20 m), with a harvest area of 1.50 m^2 (1.50 x 1.00 m), containing 75 carrot plants in spacing 0,25 x 0.04 m, containing 25 plants per linear meter and 30 vegetable cowpea plants in the 0.25 x 0.25 m spacing with 10 plants per linear meter. The 4: 4 arrangement consisted of quadruple rows of carrot alternating with quadruple rows of vegetable cowpea, flanked by the same border rows as the 2: 2 arrangement. The total area of the plot was 3.60 m² (3.00 x 1.20 m), with a harvest area of 2.00 (2.00 mx 1.00 m) m², containing 100 carrot plants in spacing 0.25 x 0.04 m with 25 plants per linear meter and 40 vegetable cowpea plants in the 0.25 x 0.25 m spacing with 10 plants per linear meter.

In each block, single plots of the carrot and cowpea crops were planted to obtain the efficiency indices of the associated systems. The single crops were established by planting six rows per plot, with 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), at a spacing of 0.20 x 0.10 m for the carrot crop, and with a total area of 3.60 m^2 (3.00 x 1.20 m) and a harvest area 2.00 m^2 (2.00 x 1.00 m) at a spacing of 0.50 x 0.10 m for the vegetable cowpea providing the plant populations recommended for the cultivation of the single crops of cowpea and carrot in the region that are 200,000 and 500,000 plants per ha, respectively, according to the methodology used by Bezerra Neto *et al.* (2014), and Vieira *et al.* (2018). The harvest areas of these crops were constituted of the four central rows of plants in each plot, excluding the first and last plants of each row, which were used as borders. In each treatment of the intercropping system was used the same plant population of the crops of each treatment of the crops in monocropping.

Soil preparation consisted of mechanical cleaning of the experimental area with the aid of a tractor with a coupled plow, followed by harrowing and mechanized lifting of the beds. After that, solarization was carried out in pre-planting with a transparent plastic type Vulca Brilho Bril Flex (30 microns) for 45 days to combat nematodes and phytoparasites in the 0-20 cm soil layer.

Green manure composed of *M. aegyptia* was collected from the native vegetation near Mossoró City, prior to flowering in each cropping year. After the collection of the plants, they were crushed in a conventional forage machine, obtaining fragmented particles with granulometry around 2.0 to 3.0 cm and subsequently sun-dried until the moisture content of 10% was reached. After this, samples of these materials was subjected to laboratory analysis, yielding the following results: N = 15.30 g kg^{-1}, P = 4.0 g kg^{-1}, K = 15.70 g kg^{-1}, Ca = 9.30 g kg^{-1}, Mg = 7.03 g kg^{-1}, and C: N ratio of 25:1 for the material collected in the first cropping year and N = 16.60 g kg^{-1}, P = 2.79 g kg^{-1}, K = 20.80 g kg^{-1}, Ca = 19.35 g kg^{-1}, Mg = 7.07 g kg^{-1}, and C:N ratio of 25:1 for the material collected in second cropping year.

The hairy woodrose (*M. aegyptia*) is a spontaneous species that sprouts every year in the rainy season in the semi-arid region of northeastern Brazil, which reaches up to 40 and 4 t ha^{-1} of green and dry biomass, respectively. It does not suffer any danger of extinction in its use as green manure in the production systems of vegetables and food crops, since every year it sprouts with rainwater. This species is widely distributed, found in forests, fences, clearings in the woods, and fields and grows in soils of different textures (GÓES, 2007). In terms of dry basis, this plant contains 2.62% N, 0.17% P, 1.20% C, 1.2% K, 0.90% Ca and 1.08% Mg, thus constituting, an excellent source of green manure for use in family farming production systems in the northeastern Brazilian region (LINHARES, 2009).

Fertilization was carried out with the dried green manure divided into two incorporations made with hoes between the planting lines in each experimental area, with 50% of the amounts incorporated at 20 days before planting and the remaining 50% at 45 days after planting (MORAIS *et al.*, 2018). The amounts of *M. aegyptia* used in single crops of vegetables were those optimized, as recommended by prior research in this region (BEZERRA NETO *et al.*, 2014).

The cultivars planted were ‘Brasília’ for carrot and ‘BRS Tumucumaque’, of indeterminate growth and semi-erect port for cowpea recommended for the cultivation in the Northeast region, both sown on Jul. 14, 2017 and 2018, in simultaneous cultivation. Thinning was performed at 18 and 12 days after sowing (DAS) for carrot and cowpea, respectively, leaving one plant per hole. During the conduction of the experiments, manual weeding was carried out. The vegetable cowpea harvests were performed from 55 to 67 and from 57 to 67 DAS, while carrots were harvested at 96 and 95 DAS in 2017 and 2018, respectively.

Irrigation was performed using a micro-sprinkler, with two daily waterings, (morning and afternoon), supplying on average 8 mm day^{-1} (COSTA *et al*., 2017) to favor soil microbial activity, with the aim to facilitate the decomposition of the green manure and to meet the water requirements of the crops, which is 350 to 550 mm for carrot and 300 to 450 mm for cowpea (FREIRE FILHO *et al*., 2011; MAROUELLI; OLIVEIRA; SILVA, 2007).

The characteristics evaluated in the carrot crop were: dry mass of shoots and roots, productivities of total and commercially viable roots, and classified productivity of roots assessed according to the length and greater diameter in long (length of 17 to 25 cm and diameter < 5 cm), medium (length 12 to 17 cm and diameter > 2.5 cm), short (length 5 to 12 cm and diameter > 1 cm), and scrap (showing cracks, bifurcations, nematodes, and/or mechanical damage) roots (FAVACHO *et al*., 2017).

In the cowpea crop, we evaluated the number of green grains per pod, the weight of 100 green grains, and yield and dry mass of green grains. In the intercropping systems, the following indicators of agro-economic efficiency were determined: land equivalent coefficient (LEC) and monetary equivalent ratio (MER).

The land equivalent coefficient was calculated using the equation $LEC = LER_c \times LER_{vc}$, proposed by Diniz *et al.* (2017), where LEC_c and LEC_{vc} represent the partial land equivalent ratios of the carrot and vegetable cowpea crops, respectively. When LEC > 25% indicates advantage of the intercropping in relation to monoculture.

The monetary equivalent ratio was determined according to the methodology proposed by Adetiloye and Adekunle (1989): $MER = (GI_{cvc} + GI_{vcc})/GI_c$, where GI_{cvc} is the gross income of carrot ($_c$) in intercropping with vegetable cowpea ($_{vc}$); GI_{vcc} is the gross income of vegetable cowpea in intercropping with carrot; GI_c is the highest gross income in single-crop *c* culture when compared with that of the *vc* culture. This index measures the economic superiority, or otherwise, of the intercrop over the most economic sole crop.

Univariate analysis of variance was performed in each cropping year in the evaluated characteristics and indices of the intercropping systems, where later, joint analysis of the two cropping years in each characteristic and index was performed, using the software package Sisvar, version 5.6: a system of computational statistical analysis (FERREIRA, 2011). To perform this analysis, it was necessary that the residual mean squares of each evaluated characteristic did not differ significantly, that is to say, that they were relatively homogeneous, being the quotient between the largest and the smallest residual mean square inferior to 7.

Tukey´s test was used to compare the means between the spatial arrangements and the F test between cropping years ($p \leq 0.05$). A procedure to adjust the regression curves was performed in the quantitative variable through the Table Curve software, version 3.0 (JANDEL SCIENTIFIC, 1991), to estimate the behavior of each characteristic or index analyzed as a function of the amounts of *M. aegyptia* biomass incorporated into the soil.

RESULT AND DISCUSSION

Based on the results of the combined analysis of variance, no significant interaction was observed between the production factors cropping years, spatial arrangements, and amounts of *M. aegyptia* biomass in any of the characteristics evaluated in the carrot crop (Table 1). However, a significant effect of cropping years was recorded on the dry mass of shoots and on the productivities of short and scrap carrot roots, with the first year standing out from the second year in terms of dry shoot mass, and with the second cropping year highlighting from the first year, in terms of productivities of short and scrap roots. In the other characteristics evaluated in the carrot crop, there was no significant effect of cropping years (Table 1).

A significant effect of spatial arrangements was observed on root dry matter and total and commercial productivities of carrot roots, with 3:3 and 4:4 arrangements surpassing the 2:2 arrangement. In terms of the other characteristics of the carrot crop, we observed no significant differences (Table 1).

The dry mass of shoots and roots, in the total and commercial productivities and in the classified productivity of long and medium carrot roots, increased as a function of increasing amounts of *M. aegyptia* biomass, with maximum values of 4.35, 2.29, 31.02, 29.47, 14.11, and 12.85 t ha^{-1} for the amounts of 61.69, 60.39, 30.45, 32.69, 39.38, and 28.95 t ha^{-1} of *M. aegyptia* biomass incorporated into the soil, with a subsequent decrease (Figures 1A, 1B, and 1C). These decreases in these characteristics after the maximum points, probably followed the Maximum Law, where the excess of a nutrient in the soil can cause a toxic effect and/or decrease the effectiveness of others, thus reducing agricultural production (ALMEIDA *et al*., 2015).

The production of short and scrap roots increased with increasing amounts of *M. aegyptia* biomass incorporated into the soil, obtaining maximum values of 3.17 and 1.59 t ha^{-1} for the amount of 65.00 t ha^{-1} of *M. aegyptia* (Figure 1D). This behavior probably occurred due to the increase in the total productivity originating from the larger amounts of fertilizer, which naturally causes an absolute increase in the waste roots.

In the northeastern semi-arid region of Brazil, farmers who practice vegetable intercropping use several production factors that interact with each other, interfering with the agronomic performance of crops (SILVA *et al*., 2018). Thus, an understanding of the competition between plants used in the intercropping system and of their individual ability to establish in this system is of great importance for the success of such systems and for a high productive potential.

The highest average values of the total production and commercially viable carrots, 28.99; 27.77 and 28.22; 27.05 t ha^{-1}, were obtained in the 4:4 and 3:3 spatial arrangements, surpassing the productions of the 2: 2 arrangement (27.21 and 25.92 t ha^{-1}). This result is possibly due in large part to lower shading by the cowpea crop, mainly in the central rows, thus providing a greater luminous intensity for the carrot crop. However, in favorable environmental conditions, with non-limiting nutrients and water, and controlled stress factors, the use of light is the most important process for productivity, because through the increase in light capture, there will be an increase in the photosynthetic rate and, consequently, in the production of photoassimilates, resulting in greater productions (LEMOS NETO *et al*., 2018).

Costa *et al.* (2017), studied carrot and vegetable cowpea intercropping in the same region, using the same cultivars of these crops in the 4:4 arrangement, and recorded maximum values for total and commercial productivity of viable roots of 26.27 and 24.78 t ha^{-1}, respectively. These differences are most likely due to the different cropping years.

The production of long (13.33 t ha^{-1}) and short (2.54 t ha^{-1}) roots obtained in this study was also higher when compared to the study of Costa *et al.* (2017), who obtained value of 6.76 and 1.73 t ha^{-1}, respectively.

The increasing in the carrot productivity was likely due to a result of the higher amounts of nitrogen (N) and potassium (K) with increasing amounts of *M. aegyptia* biomass, since carrot contained 15.30 and 15.70 g kg^{-1} of nitrogen and potassium, respectively, in the first cropping year, and 16.60 and 20.80 g kg^{-1}, respectively, in the second year. Thus, increasing the amounts of these nutrients favored plant development, resulting in a greater productive performance.

Another important aspect is the carbon: nitrogen (C:N) ratio of the material used, since this ratio is linked to the rate of decomposition of organic waste. For *M. aegyptia*, the C: N ratio was 25:1. According to Bezerra Neto *et al.* (2014), when organic residues have a C: N ratio between 20: 1 and 30: 1, there is no predominance of immobilization or mineralization of N. Besides the availability of this nutrient supplied by increasing amounts of *M. aegyptia*, this fertilizer influenced the physical, chemical and, biological properties of the soil, resulting in a greater capacity to store nutrients.

Based on the results of the joint analysis of the variables evaluated for vegetable cowpea, a significant interaction was observed between cropping years and spatial arrangements and between spatial arrangements and amounts of *M. aegyptia* biomass incorporated into the soil in terms of yield of green grains of cowpea (Table 2).

Table 1 - F values and mean values for dry mass of shoots (DMS) and roots (DMR), productivities of total (PTR) and commercially viable (PCR) roots, productivities of long roots (PLR), medium roots (PMR), short roots (PSR), and scrap roots (PScR) of carrot intercropped with vegetable cowpea at two cropping years and in different spatial arrangements

Sources of variation	DMS	DMR	PTR	PCR	PRL	PRM	PRC	PScR
	t ha^{-1}							
Blocks (Cropping years)	0.91^{ns}	1.30^{ns}	1.29^{ns}	1.25^{ns}	0.97^{ns}	0.42^{ns}	1.50^{ns}	0.89^{ns}
Cropping years (Y)	66.87**	0.00^{ns}	0.10^{ns}	0.86^{ns}	3.06^{ns}	0.00^{ns}	13.72**	6.16*
Amounts of *M. aegyptia* (Q)	10.31**	0.59^{ns}	11.69**	11.10**	4.59**	3.31*	2.75*	6.49**
Spatial arrangements (A)	2.85^{ns}	5.24**	3.10*	3.07*	1.40^{ns}	1.34^{ns}	1.03^{ns}	0.21^{ns}
Y x Q	1.13^{ns}	0.93^{ns}	1.27^{ns}	0.94^{ns}	0.20^{ns}	0.42^{ns}	0.13^{ns}	1.39^{ns}
Y x A	0.09^{ns}	0.60^{ns}	2.25^{ns}	1.48^{ns}	1.23^{ns}	1.06^{ns}	0.53^{ns}	0.74^{ns}
Q x A	1.10^{ns}	0.95^{ns}	0.78^{ns}	1.03^{ns}	0.51^{ns}	0.95^{ns}	1.07^{ns}	1.32^{ns}
Y x Q x A	0.83^{ns}	0.92^{ns}	1.66^{ns}	1.63^{ns}	0.24^{ns}	1.39^{ns}	0.33^{ns}	0.50^{ns}
CV (%)	16.23	17.73	10.18	11.22	28.85	17.45	34.86	32.69
Cropping years	Mean values							
1	4.45 a†	2.20 a	28.23 a	27.19 a	13.15 a	11.68 a	2.36 b	1.04 b
2	3.39 b	2.19 a	28.05 a	26.62 a	11.86 a	11.68 a	3.08 a	1.43 a
	Spatial arrangement							
2:2	3.70 a	2.04 b	27.21 b	25.92 b	11.85 a	11.20 a	2.87 a	1.29 a
3:3	4.01 a	2.19 a	28.22 a	27.05 a	12.34 a	11.94 a	2.77 a	1.17 a
4:4	4.05 a	2.38 a	28.99 a	27.77 a	13.33 a	11.90 a	2.54 a	1.22 a

** = P<0.01; * = P<0.05; ns = P>0.05. † Means followed by different lowercase letters within a column differ statistically by F or Tukey´s test at the 5% probability level

Figure 1 - Dry mass of shoots and roots (A), productivity of total and commercially viable roots (B), productivity of long and medium roots (C), and productivity of short and scrap roots (D) of carrot intercropped with vegetable cowpea as a function of amounts of *M. aegyptia* biomass

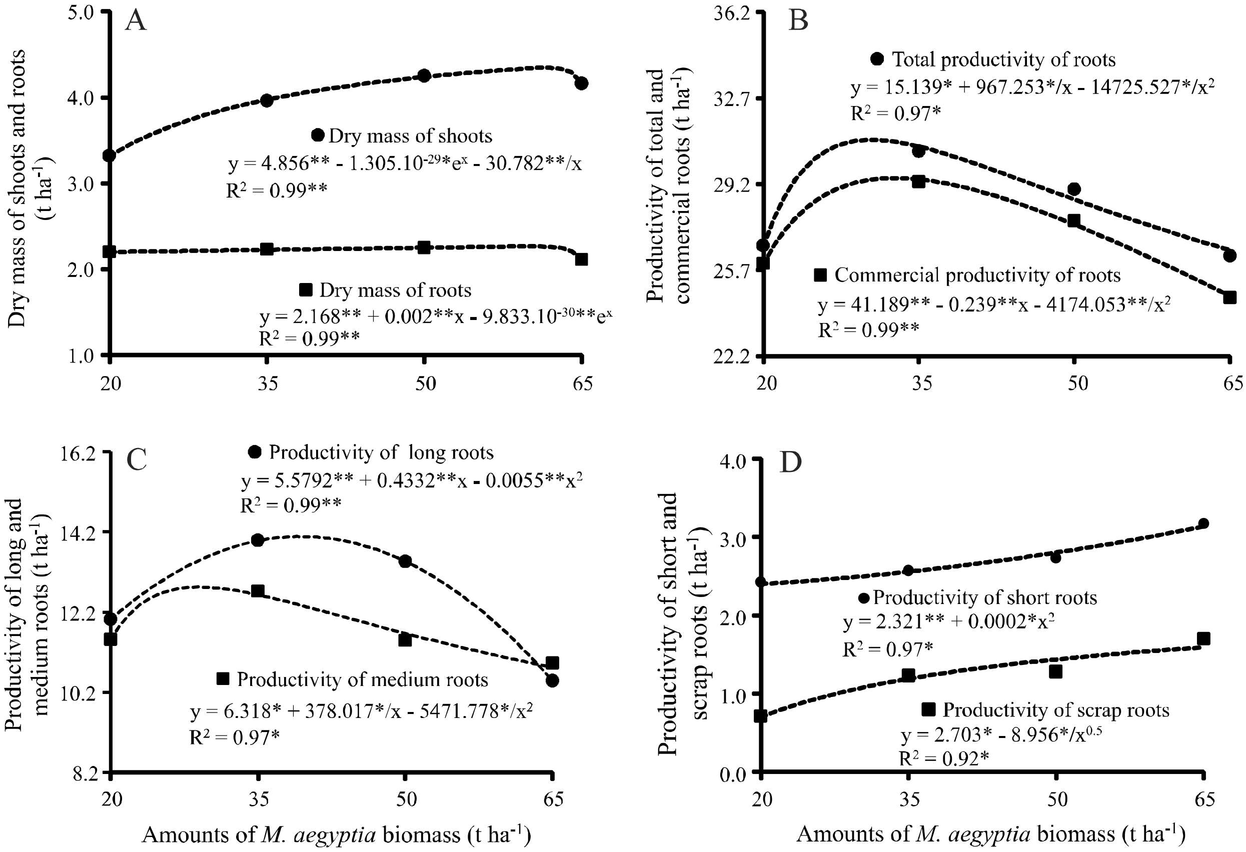


Table 2 - F values for number of green grains per pod (NGGP), weight of 100 green grains (W100GG), yield of green grains (YGG), and dry matter of green grains (DMGG) of vegetable cowpea intercropped with carrot at two cropping years, different amounts of *M. aegyptia*, and in different spatial arrangements

Sources of variation	NGGP	W100GG	YGG	DMGG
Blocks (Cropping years)	1.29^{ns}	1.37^{ns}	0.93^{ns}	1.99^{ns}
Cropping years (Y)	39.04**	4.75*	158.25**	107.75**
Amounts of *M. aegyptia* (Q)	13.39**	6.20**	34.86**	27.59**
Spatial arrangements (A)	1.45^{ns}	1.06^{ns}	136.87**	2.98^{ns}
Y x Q	1.52^{ns}	0.29^{ns}	1.16^{ns}	1.13^{ns}
Y x A	0.17^{ns}	0.15^{ns}	24.89**	2.91^{ns}
Q x A	1.37^{ns}	1.58^{ns}	2.94*	1.07^{ns}
Y x Q x A	0.87^{ns}	0.65^{ns}	1.50^{ns}	0.89^{ns}
CV (%)	8.19	5.00	18.27	22.52

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

Studying the cropping years in each spatial arrangement, we observed that the yield of green grains in the second cropping year stood out from that obtained in the first year in all spatial arrangements. On the other hand, analyzing the spatial arrangements in each cropping year, we recorded higher yields of green grains in the 2:2 spatial arrangement, irrespective of the cropping year (Table 3).

Table 3 - Mean values for the yield of green grains (YGG), number of green grains per pod (NGGP), weight of 100 green grains (W100GG), and dry matter of green grains (DMGG) of vegetable cowpea intercropped with carrot at two cropping years, different amounts of *M. aegyptia*, and in different spatial arrangements

Cropping years	YGG (t ha^{-1})		
	Spatial arrangements		
	2:2	3:3	4:4
1	1.55b A*	1.09b B	0.89b B
2	2.84a A	1.62a B	1.25a C
	Amounts of *M. aegyptia* (t ha^{-1})		
20	1.51 A	0.89 B	0.79 B
35	2.27 A	1.50 B	0.95 C
50	2.70 A	1.56 B	1.32 B
65	2.28 A	1.48 B	1.22 B
Cropping years	NGGP	W100GG (g)	DMGG (t ha^{-1})
1	9.60 b	38.85 a	0.63 b
2	10.70 a	37.99 b	1.02 a
	Spatial arrangements		
2:2	10.00 a	38.09 a	0.88 a
3:3	10.10 a	38.38 a	0.77 b
4:4	10.34 a	38.78 a	0.82 ab

*Means followed by different lowercase letters within a column or uppercase letter within a row differ statistically by F or Tukey´s test at the 5% probability level

By studying the spatial arrangements in each amount of *M. aegyptia* biomass, the arrangement 2:2 stood out from the others, irrespective of the biomass amount (Table 3).

On the other hand, partitioning the significant interaction amounts of *M. aegyptia* biomass in each spatial arrangement in the yield of green grains, the yield increased with increasing manure amounts, reaching maximum values of 3.13, 1.56, and 1.49 t ha^{-1} at amounts of 50.17, 44.47, and 55.88 t ha^{-1} in the spatial arrangements (SA) 2:2, 3:3, and 4:4 respectively, with a subsequent decrease (Figure 2C).

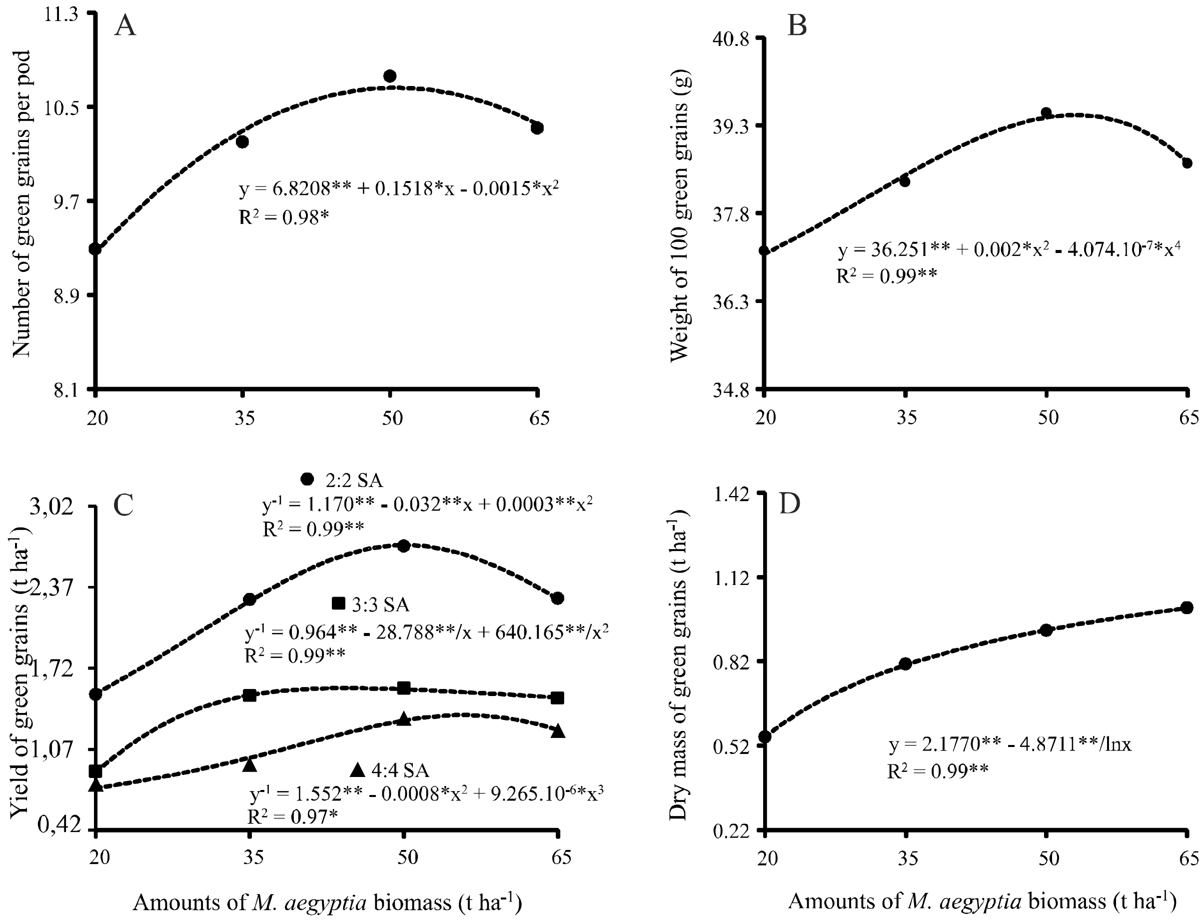
The mean values of the number of green grains per pod and of the dry mass of green grains were higher in the second cropping year than in the first year. However, an opposite behavior was observed for mean weight of 100 green grains, where the average values of the first cropping year were statistically higher than those of the second year (Table 3).

In terms of the spatial arrangements, a significant difference was recorded only for the dry mass of green grains, with the 2:2 arrangement surpassing the 3:3 and 4:4 arrangements (Table 3).

Growing behavior as a function of increasing amounts of *M. aegyptia* biomass was also observed for the number of green grains per pod and the weight of 100 green grains up to the maximum values of 10.7 grains per pod and 38.65 g for *M. aegyptia* biomass amounts of 50.61 and 53.05 t ha^{-1}, respectively, with a subsequent decrease (Figures 2A and 2B). For the dry mass of green grains, an increasing behavior was observed with increasing amounts of *M. aegyptia* biomass, obtaining the maximum value of 1.01 t ha^{-1} at the highest amount of *M. aegyptia* of 65 t ha^{-1} (Figure 2D).

The highest values, observed in the second cropping year (Table 3), for the number of green grains per pod, productivity, and dry mass of green grains are related to the highest amount of phosphorus present in the soil, with values of 22.80 mg dm^{-3}, being significantly higher than in the first year (10.30 mg dm^{-3}). This finding is in agreement with the observations of Brasil and Nascimento (2010), who reported that P has great importance in the initial plant growth in terms of energy storage and transfer, being directly involved in the active absorption of nutrients. This higher amount of phosphorus present in the soil in the second cropping year may have resulted in better-nourished cowpea plants, with intense development and a short cycle. Therefore, an adequate availability of this nutrient in the initial phase becomes of great importance for the development of metabolic functions and initial formation of the plants, thus providing an increase in the

Figure 2 - Number of green grains per pod (A), weight of 100 green grains (B), and dry mass of vegetable cowpea green grains (D) as a function of amounts of *M. aegyptia* biomass, and yield of vegetable cowpea green grains (C) intercropped with carrot as a function of amounts of *M. aegyptia* biomass and spatial arrangements



number of pods and consequently higher yield of green grains.

The higher yield and dry mass of green grains obtained in the 2:2 space arrangement may be associated with the greater intraspecific competition. Most likely, in the spatial arrangement with less intraspecific competition, compensation was greater, with a higher concentration of photoassimilates by cowpea due to the better use of available natural resources.

These results differ from those observed by Favacho *et al.* (2017), who, when analyzing these characteristics as a function of the spatial arrangements 2:2, 3:3, and 4:4, did not observe any significant differences. Likewise, Nunes *et al.* (2018), studying the intercropping of radish with cowpea, did not register any significant differences among the spatial arrangements for these characteristics.

The increasing values of the evaluated characteristics of cowpea with increasing amounts of *M. aegyptia* biomass (Figure 2) are due to the beneficial effects provided by this fertilization technique, including increased nutrient amounts, mainly in terms of nitrogen, higher organic matter contents, and decreased acidity and in aluminum levels (BEZERRA NETO *et al*., 2014), in addition to an improved soil fertility, water retention, and microbial soil activity (GRAHAM; HAYNES, 2006).

Based on the results of the joint analysis of the indicators of agro-economic efficiency of the intercropping of carrot with vegetable cowpea, a significant interaction was observed between cropping years and spatial arrangements and between amounts of *M. aegyptia* biomass and spatial arrangements for the land equivalent coefficient (Table 4).

Partitioning the interaction of cropping years in each spatial arrangement, higher average values of this index were recorded in the second cropping year in each arrangement. On the other hand, studying the spatial arrangements in each cropping year, the 2:2 arrangement

Table 4 - F values for the land equivalent coefficient (LEC) and equivalent monetary ratio (MER) of carrot intercropped with vegetable cowpea at two cropping years, different amounts of *M. aegyptia*, and in different spatial arrangements

Sources of variation	LEC	MER
Blocks (Cropping years)	0.57^{ns}	1.14^{ns}
Cropping years (Y)	188.75**	2.26*
Amounts of *M. aegyptia* (Q)	30.52**	16.12**
Spatial arrangements (A)	74.98**	1.36^{ns}
Y x Q	0.80^{ns}	1.08^{ns}
Y x A	24.23**	0.36^{ns}
Q x A	2.71*	0.68^{ns}
Y x Q x A	0.30^{ns}	1.15^{ns}
CV (%)	19.61	9.58

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

resulted in the highest values, irrespective of the cropping year (Table 5).

Partitioning the spatial arrangements in each amount of *M. aegyptia* biomass, the highest LEC values were recorded in the spatial arrangement 2:2 (Table 5).

Studying the interaction of the amounts of *M. aegyptia* biomass in each spatial arrangement, increasing LEC values were observed as a result of increasing amounts of *M. aegyptia* up to the maximum values of 1.14, 0.78, and 0.51 in the spatial arrangements 2:2, 3:3, and 4:4, respectively, for the amounts of 37.29, 39.96, and 53.92 t ha^{-1} of *M. aegyptia* added to the soil, with a subsequent decrease (Figure 3A).

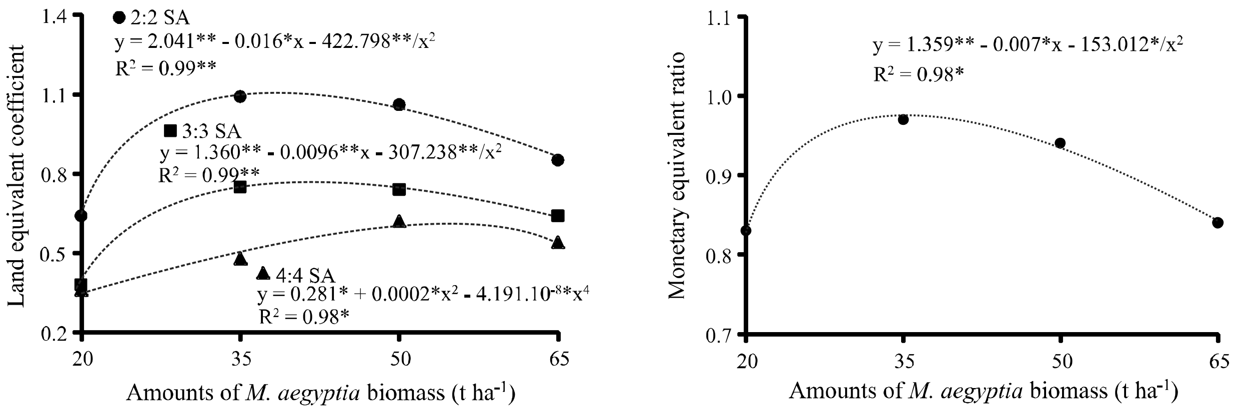
For MER, there was no significant interaction between cropping years and spatial arrangements, between cropping years and amounts of *M. aegyptia* biomass, and

Table 5 - Mean values of the land equivalent coefficient (LEC) and equivalent monetary ratio (MER) of carrot intercropped with vegetable cowpea at two cropping years, different amounts of M. aegyptia, and different spatial arrangements

Cropping years	LEC		
	Spatial arrangement		
	2:2	3:3	4:4
1	0.60b A	0.50b AB	0.41 bB
2	1.26a A	0.79a B	0.62 aC
Amounts of *M. aegyptia* (t ha^{-1})	2:2	3:3	4:4
20	0.66 A	0.40 B	0.38 B
35	1.11 A	0.77 B	0.50 C
50	1.08 A	0.76 B	0.64 B
65	0.87 A	0.66 B	0.56 B
Cropping years	MER		
1	0.92 a		
2	0.88 b		
	Spatial arrangements		
2:2	0.92 a		
3:3	0.89 a		
4:4	0.89 a		

* Means followed by different lowercase letters within the same column or uppercase letters within the same row differ statistically Tukey`s test at the 5% probability level

Figure 3 - Land equivalent coefficient (A) of the intercropping system as a function of amounts of *M. aegyptia* biomass and spatial arrangements, and monetary equivalent ratio (B) of the intercropping system as a function of amounts of *M. aegyptia* biomass



between spatial arrangements and amounts of *M. aegyptia* biomass. The highest MER value was observed in the first cropping year. There were no significant differences in the mean values of MER among the spatial arrangements (Table 5).

A crescent behavior as a function of increasing amounts of *M. aegyptia* biomass was also observed for the MER value up to the maximum value of 0.99 for a biomass amount of 34.66 t ha^{-1}, with a subsequent decrease (Figure 3B).

The highest value observed for the land equivalent coefficient (LEC) in the second cropping year, in the 2:2 spatial arrangement of 1.26 (Table 5), is related to the higher yield of green cowpea grains, which almost doubled in the second cropping year when compared with the first cropping year (Table 3).

This result reflects the greater viability of this cropping system, with a yield advantage of the intercropped crop in relation to the single crop. The observed value of 1.26 was higher than that observed by Oseni and Aliyu (2010) when intercropping sorghum with cowpea in a semi-arid region of Nigeria in two agricultural years, obtaining a value of 1.16 in the 1:1 planting arrangement.

Regarding the highest values observed for LEC and MER of 1.14 and 0.99, respectively, at biomass amounts of 37.29 and 34.66 t ha^{-1} (Figures 3A and 3B), they are probably due to the greater nutrient availability provided by the green manure, apart from the higher levels of nitrogen. Thus, since the plants were well nourished, they could accumulate high amounts of dry matter, which corresponds to a photosynthetically active leaf area with enough capacity for the assimilated translocation, resulting in an optimal productive capacity (FAVACHO *et al.*, 2017).

On the other hand, the highest observed value for LEC of 1.26 in the 2:2 spatial arrangement is related to the greater interspecific competition exerted by the cowpea crop in this spatial arrangement (Table 5). This is confirmed by the green grain yield data for the cowpea crop (Table 3), where the highest yield of 2.84 was observed in the 2:2 spatial arrangement, which was almost twice as high as those obtained in the 3:3 (1.62 t ha^{-1}) and 4:4 (1.25 t ha^{-1}) spatial arrangements. This leads us to infer that the 2:2 spatial arrangement provided a greater agronomic viability of the intercropped crops.

CONCLUSIONS

1. The production optimization of the carrot and cowpea cultures was achieved with the incorporation of *M. aegyptia* biomass into the soil at amounts of 32.69 and 50.17 t ha^{-1}, respectively;
2. Agro-economic optimization of the cowpea-carrot intercropped system was obtained at the *M. aegyptia* biomass amount of 34.66 t ha^{-1} added to the soil;
3. The 2:2 spatial arrangement provided the greatest agro-economic efficiency, with a better productive performance of the cowpea crop.
4. The *M. aegyptia* species used as green manure proved to be viable to the family farmers that practice the intercropping of carrot and vegetable cowpea.

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