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OPTIMIZED PRODUCTION OF IMMATURE COWPEA UNDER GREEN MANURING IN A SEMI-ARID ENVIRONMENT[1]

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ABSTRACT - Given the lack of information on the use of spontaneous plants from the Caatinga biome as green manure to produce green grains, the present work aimed to agronomically and economically optimize cowpea production for green grains and their components when fertilized with equitable biomass amounts of hairy woodrose (*Merremia aegyptia* L.) and roostertree (*Calotropis procera* Ait.) in two cropping seasons in a semi-arid environment. The experiment used a randomized complete block design, with five treatments and five replicates. The treatments consisted of equitable amounts of dry *M. aegyptia* and *C. procera* biomass of 16, 29, 42, 55 and 68 t ha^{-1}. In each experiment, an additional treatment was planted with cowpea without fertilizer (absolute control), and another was fertilized with mineral fertilizer for the purpose of comparison with the treatment of maximum physical or economic efficiency. The maximum optimized physical (agronomic) efficiencies of cowpea green pods and grain production were reached in the productivity of green pods at 3.90 t ha^{-1} and green grains at 4.06 t ha^{-1}, with incorporation into the soil of 45.07 and 50.48 t ha^{-1} of green manure, respectively. The maximum economic efficiency of cowpea green grain production was reached at a net income of R$5826.12 ha^{-1} and at a rate of return of 1.29 reals for each real invested with application to the soil of 38.74 and 37.85 t ha^{-1} of the tested green manure biomass.

Keywords: *Vigna unguiculata*. *Merremia aegyptia*. *Calotropis procera*. Agro-economic optimization.

PRODUÇÃO OTIMIZADA DE FEIJÃO-CAUPI IMATURO SOB ADUBAÇÃO VERDE EM AMBIENTE SEMIÁRIDO

RESUMO - Diante da falta de informações sobre o uso de plantas espontâneas do bioma Caatinga como adubos verdes para produção de grãos verdes, esse trabalho teve como objetivo otimizar agronômica e economicamente a produção de feijão-caupi para grãos verdes e de seus componentes quando adubado com quantidades equitativas de biomassa das espécies jitirana (*Merremia aegyptia* L.) e flor-de-seda (*Calotropis procera* Ait.) em duas estações de cultivos em ambiente semiárido. O delineamento experimental utilizado foi em blocos completos casualizados, com cinco tratamentos e cinco repetições. Os tratamentos consistiram de quantidades equitativas de biomassa de jitirana (*Merremia aegyptia*) e de flor-de-seda (*Calotropis procera*) nas doses de 16, 29, 42, 55 e 68 t ha^{-1} em base seca. Em cada experimento foi plantado um tratamento adicional com feijão-caupi sem adubo (testemunha absoluta) e outro adubado com fertilizante mineral para efeito de comparação com o tratamento de máxima eficiência fisica ou econômica. As máximas eficiências físicas (agronômicas) otimizadas da produção de vagens e grãos verdes de feijão-caupi foram alcançadas na produtividade de vagens verdes de 3,90 t ha^{-1} e na produtividade de grãos verdes de 4,06 t ha^{-1}, com a incorporação ao solo de 45,07 e 50,48 t ha^{-1} de biomassa dos adubos verdes, respectivamente. A máxima eficiência econômica da produção de grãos verdes do feijão-caupi foi alcançada na renda líquida de 5.826,12 R$ ha^{-1} e na taxa de retorno 1,29 reais por cada real investido com aplicação ao solo de 38,74 e 37,85 t ha^{-1} de biomassa dos adubos verdes testados.

Palavras-chave: *Vigna unguiculata*. *Merremia aegyptia*. *Calotropis procera*. Otimização agroeconômica.

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INTRODUCTION

Cowpea [*Vigna unguiculata* (L) Walp.] is a legume of great social, nutritional and economic importance in tropical and subtropical regions of the world. It is cultivated in more than 100 countries and generates employment and income for thousands of people (OLIVEIRA et al., 2021). In Brazil, cowpea is grown mostly in the north and northeast regions, where it is a staple food for the lower purchasing power classes (FREIRE FILHO; COSTA, 2020). It can be found in important supermarkets and in many restaurants in different capitals in the country. In nutritional terms, this legume constitutes an important source of protein (23 to 25%, on average) and carbohydrates, standing out for its high content of dietary fiber, vitamins and minerals, in addition to having a low amount of lipids (2%, on average) (SILVA et al., 2016).

Due to its great genetic variability, this crop is used for various purposes in different production systems and can be marketed in the form of dry grain, green grain, green pods and seeds, but the cowpea market mainly revolves around the production of dry grain and green or immature grain (RAMOS et al., 2015). In the form of green or immature grain, the cowpea crop in this type of production system is treated as a vegetable by rural families, calling it vegetable-cowpea, as its production represents an alternative source of income for these producers (COSTA et al., 2017).

The need to increase its productivity, improve the quality of its product and reduce production costs makes it necessary to determine the interference of factors such as cultivar and organic fertilization (green manure) in researchers, extensionists and producers. Lately, the use of green manuring with spontaneous species from the Caatinga biome has been one of the management practices used in the organic cultivation of vegetables in the northeastern semi-arid region (SANTANA et al., 2021; SILVA et al., 2021a,b).

Hairy woodrose (*Merremia aegyptia* L.) and roostertree (*Calotropis procera* Ait.) are among these species of green manure. According to Linhares et al. (2012), these species have the qualities of “good fertilizers,” as they have a good supply of nutrients, excellent biomass production and a low C/N ratio, which enables faster decomposition and a steady supply of nutrients to plants.

Research carried out in the Brazilian semi-arid region with spontaneous species of hairy woodrose and roostertree as green manure in single crops of beet and radish vegetables (LINO et al., 2021a) and in intercropped radish and arugula vegetables (SÁ et al., 2021), beets and lettuce (GUERRA et al., 2021), and beets and arugula (LINO et al., 2021b) have shown promising bio-economic returns.

Given the lack of information on the use of these spontaneous species as green manure in the single cropping of cowpea for the production of green grain, the present work aimed to agronomically and economically optimize the production of cowpea for green grain and its components when fertilized with equitable biomass amounts of the spontaneous species hairy woodrose and roostertree from the Caatinga biome in two cropping seasons.

MATERIAL AND METHODS

Experiments were conducted from December 2020 to February 2021 and from October to December 2021 at the Rafael Fernandes Experimental Farm, belonging to the Universidade Federal do Rural do Semi-Árido (UFERSA), located in the district of Alagoinha, approximately 20 km from Mossoró-RN, under a latitude of 5º 03' 37” S, longitude of 37º 23’ 50” W and altitude of 80 m.

The climate of the region, according to the Köppen Geiger classification, is dry and very hot, with two seasons: a dry season starting in June and ending in January and a rainy season starting in February and ending in May (BECK et al., 2018). During cowpea development and growth periods, the average values recorded for minimum, average and maximum temperatures were 24.8, 29.3, and 35.9°C, respectively, in 2020 and 23.9; 29.4 and 36.8°C, respectively, in 2021. The relative air humidity was 61.1 and 58.5%, precipitation was 39.96 and 26.04 mm, solar radiation was 19.3 and 21.1 MJ m^{-2} day^{-1}, and wind speed was 6.4 and 6.5 m s^{-1} in 2020 and 2021, respectively (INMET, 2021). The average temperature and average daily relative humidity data after cowpea sowing during the two crops are shown in Figure 1.

The soil in the experimental cultivation areas was classified as typical Dystrophic Red Yellow Argisol, with a sandy loam texture (SANTOS et al., 2018). In each experimental area, simple soil samples were collected from the surface layer (0–20 cm) and homogenized to obtain a composite sample representative of the area. Following EMBRAPA (2017), chemical analysis of the soil showed the following parameters: pH (water) = 6.3; EC = 0.44 dS m^{-1}; O.M. = 11.90 g kg^{-1}; N = 0.60 g kg^{-1}; P = 24.00 mg dm^{-3}; K = 52.28 mg dm^{-3}; Ca=22.50 $cmol_c$ dm^{-3}; Mg = 4.80 $cmol_c$ dm^{-3}; Na = 1.73 mg dm^{-3}; Cu = 0.50 mg dm^{-3}; Fe = 5.70 mg dm^{-3}; Mn = 11.20 mg dm^{-3}; and Zn = 3.80 mg dm^{-3}. In the soil from 2021, these parameters were as follows: pH (water) = 6.6; EC = 0.56 dS m^{-1}; O.M. = 12.97 g kg^{-1}; N = 0.65 g kg^{-1}; P = 32.00 mg dm^{-3}; K = 61.27 mg dm^{-3}; Ca = 23.70 $cmol_c$ dm^{-3}; Mg = 6.50 $cmol_c$ dm^{-3}; Na = 2.30 mg dm^{-3}; Cu = 0.30 mg dm^{-3}; Fe = 4.80 mg dm^{-3}; Mn = 6.10 mg dm^{-3}; and Zn = 2.70 mg dm^{-3}.

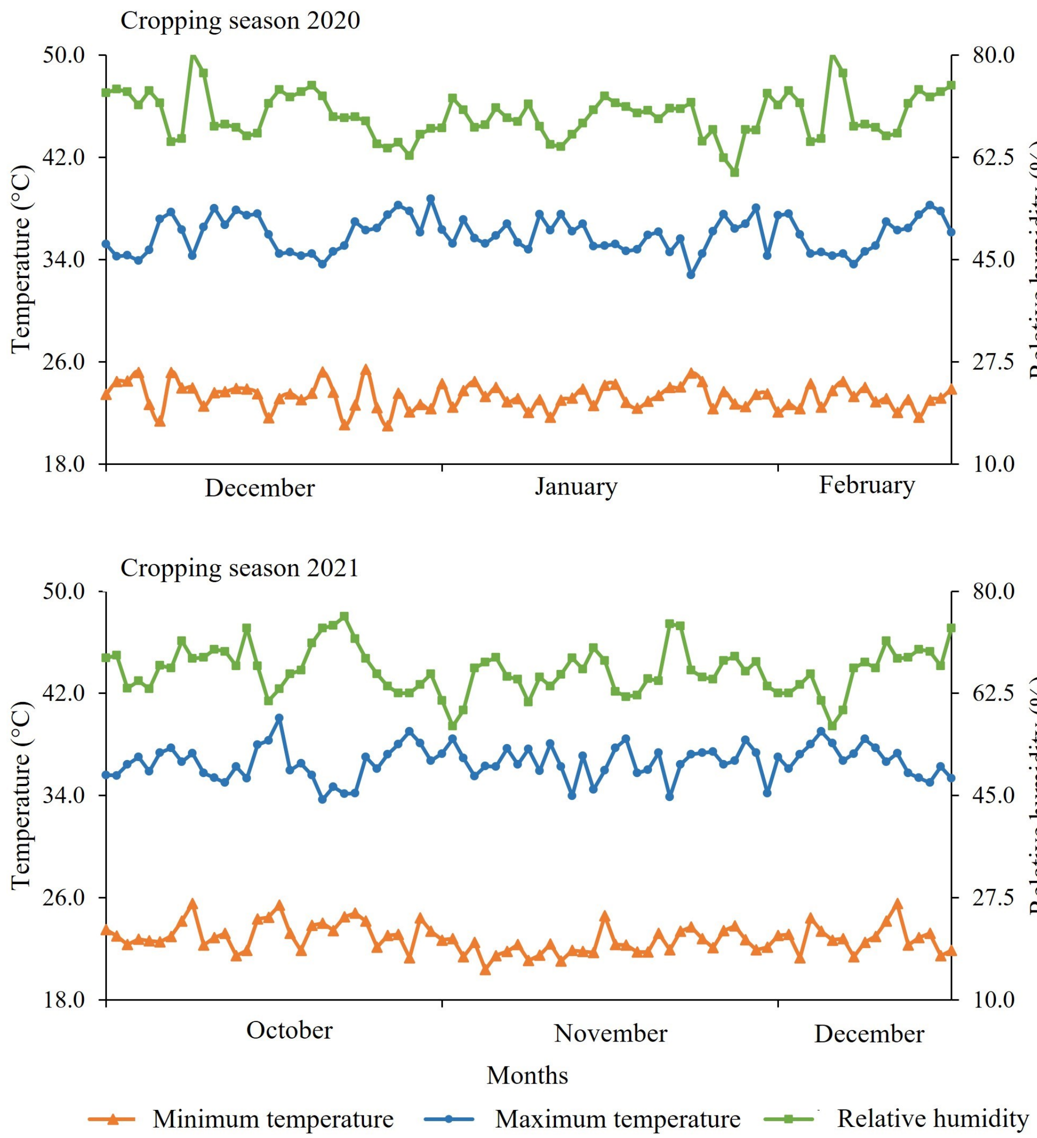

Figure 1. Daily temperature and relative humidity data during cowpea cropping seasons in 2020 and 2021.

The experiment was organized in a randomized complete block design, with five treatments and five replicates. The treatments consisted of equitable amounts of dry hairy woodrose (*Merremia aegyptia*) and roostertree (*Calotropis procera*) biomass at doses of 16, 29, 42, 55 and 68 t ha^{-1}. In each experiment, one treatment with cowpea without fertilizer (absolute control) and another fertilized with mineral fertilizer (control) were planted for comparison with the treatment to determine maximum physical and economic efficiency. The treatment of cowpea mineral fertilization consisted of the application of N, P_2O_5 and K_2O in the foundation at doses of 20, 80 and 40 kg ha^{-1}, respectively, and in coverage of 20 kg ha^{-1} of N and 20 kg ha^{-1} of K_2O, applied 15 days after sowing (HOLANDA et al., 2017).

Each experimental plot of the experiments consisted of six rows of cowpea, with 12 plants per row planted at a spacing of 0.50 m × 0.10 m, for an estimated population of 200,000 plants per hectare (PEREIRA et al., 2016). The total area of the experimental plot was 3.60 m², with a useful area of 2.00 m² (Figure 2).

Cowpea cultivar 'BRS Tumucumaque,' which has a semi-erect shape, resistance to lodging, an early cycle (65 to 75 days), modern architecture and grains of great commercial acceptance, was sown. It has good protein content, is rich in iron and zinc, cooks quickly, and has an excellent visual appearance after cooking (SILVA, 2019). It has been indicated for cultivation in the northeast region of Brazil by family and business farmers under rainfed and irrigated systems, with an average productivity of 1100 to 1703 kg ha^{-1}.

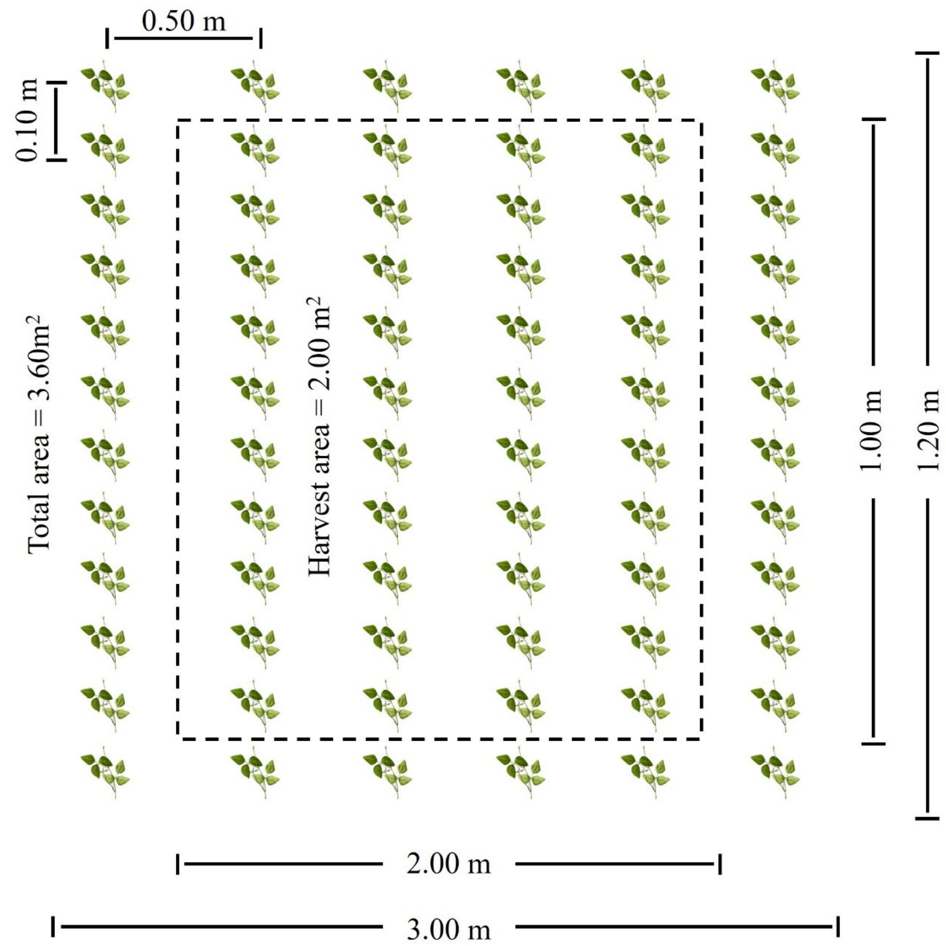

Figure 2. Graphical representation of an experimental plot of a single cowpea planted at a spacing of 0.50 × 0.10 m.

Prior to the installation of the experiments, the area was cleaned mechanically using a tractor with which plowing and harrowing were carried out. The beds were then lifted using a rotary tiller. Then, 30 micron Vulca Brilho Bril Flex transparent plastic was placed in the beds to solarize them for 30 days to reduce or eliminate the population of nematodes and weeds, especially *Meloidogyne* spp., in the layer of 0–10 cm of the soil that can harm the development of the cowpea crop (PEREIRA et al., 2016).

After solarization, two incorporations of the green manure biomass (*M. aegyptia* and *C. procera*) were carried out manually with hoes in the 0–20 m soil layer in the experimental plots, following the equitable amounts specified in the treatments. Twenty days before sowing, 30% of the green manure biomass was incorporated, and the remaining 70% was incorporated 20 days after sowing (DAS). In the first year of cultivation, this first incorporation was carried out on 11/26/2020 and the second on 01/06/2021, while in the second year, the first incorporation was carried out on 09/03/2021, and the second on 10/14/2021.

Irrigation by a micro-sprinkler system were performed daily in two shifts, morning and afternoon, throughout the experiment, providing a water depth of 8 mm applied each day to maintain the soil at field capacity. Microorganisms in the soil and the low C/N ratio of green manure favor the mineralization processes of organic matter. The amount of water supplied daily to the plants was based on the average Kc of the cowpea crop of 0.87 (OLIVEIRA, 2019).

The green manure used for cowpea fertilization was comprised of hairy woodrose (*Merremia aegyptia*) and roostertree (*Calotropis procera*), collected from the native vegetation in several places in the rural area of the municipality of Mossoró, RN, before the beginning of flowering. After collection, the plants were crushed into fragments of two to three centimeters and dehydrated at room temperature until they reached a moisture content of 10%. They were subsequently subjected to laboratory analysis to determine their chemical composition. In 2020, the chemical composition was N = 16 .60 g kg^{-1}; P = 2.79 g kg^{-1}; K = 37.80 g kg^{-1}; Mg = 7.07 g kg^{-1}; and Ca = 19.35 g kg^{-1} for hairy woodrose and N = 21.90 g kg^{-1}; P = 1.92 g kg^{-1};

K = 20.90 g kg^{-1}; Mg = 9.22 g kg^{-1}; and Ca = 17.00 g kg^{-1} for roostertree. In 2021, the chemical composition was N = 15.30 g kg^{-1}; P = 4.00 g kg^{-1}; K = 25.70 g kg^{-1}; Mg = 7.03 g kg^{-1}; and Ca = 9.30 g kg^{-1} for hairy woodrose and N = 18.40 g kg^{-1}; P = 3.10 g kg^{-1}; K = 24.50 g kg^{-1}; Mg = 13.50 g kg^{-1}; and Ca = 16.30 g kg^{-1} for roostertree.

Cowpea sowing was carried out manually in 5 cm deep holes using 2 to 3 seeds per hole on December 17, 2020, in the first year of cultivation and in the second year on September 24, 2021. Thinning was performed between 8 and 10 days after planting, leaving only one plant per hole. Whenever necessary, manual weeding was carried out. During the development of the culture, the product Agro-mos (1 ml L^{-1}), composed of nutrients, amino acids and polysaccharides, was applied with the objective of activating the natural defenses of the plants, making them naturally stronger and resistant.

Cowpeas were harvested four times in the first year of cultivation on the following dates: February 04 (50 DAS), 08 (54 DAS), 11 (57 DAS) and 17 (63 DAS) of 2021. In the second year of cultivation, five harvests were carried out on the following dates: 17 (54 DAS), 22 (59 DAS), 25 (62 DAS) and 29 (66 DAS) of November and on the 3rd (70 DAS) of December 2021. The harvesting point of the cowpea pods was determined by observing the color of the pods when they were green, not yellowish, swollen, uniform and well grained to provide a green grains weight/green pods weight ratio greater than 60%.

The following agronomic characteristics were evaluated in the cowpea plants at the end of harvest: plant height (determined in a random sample of 20 plants from the harvest area, measuring each plant with a ruler from the ground level to the base of the highest leaf, dividing the sum of measurements by 20, expressed in cm); pod length (obtained from a sample of 20 plants, measuring the length of all pods separately with the aid of a ruler and dividing the sum of the measurements by 20, expressed in cm); number of green pods per plant (obtained by quantifying the number of green pods taken from a random sample of 20 plants from the harvest area, dividing the total number of pods by 20); green pod productivity (quantified from all pods harvested from plants in the harvest area, expressed in t ha^{-1}); number of green grains per pod (obtained from a random sample of 20 pods from the useful area of each plot, counting the number of beans from the threshed pods and dividing their number by 20); weight of 100 green grains (determined from four samples of 100 grains, which were weighed, and the average weight of these samples was obtained in grams); green grain productivity (quantified of all green grains harvested from pods in the harvest area, expressed in t ha^{-1}) and dry mass of green grains (obtained from a sample of 20 plants, weighing the dry mass of green grains after drying in an oven with forced air circulation at a temperature of 65°C to a constant weight, expressed in t ha^{-1}).

In addition to agronomic characteristics, the following economic indicators were quantified. Gross income (GI), expressed in R$ ha^{-1}, was obtained by multiplying the productivity of cowpea green grains in each treatment by the value of the product paid to the producer in the region in December 2021 (R$ 7.00 per kilogram). The net income (NI) was obtained by subtracting the total production costs from the inputs and services performed in each treatment from the gross income and was expressed in R$ ha^{-1}. Total production costs were calculated for each treatment by taking into account the cost coefficients of inputs and services used in one hectare of cowpea at the experimental level. These total costs were composed of variable costs, fixed costs and opportunity costs. Variable costs comprised costs of input, labor, electricity, other expenses, and maintenance and upkeep of machinery and construction structures. Fixed costs comprised the depreciation of machinery, construction and materials used, taxes and fees, and fixed labor. Opportunity costs comprised costs with remuneration for land and remuneration with fixed capital. In the tested doses of green manure of 16, 29, 42, 55 and 68 t ha^{-1}, the average total costs per treatment were R$17,987.69, R$21,907.69, R$25,357.69, R$28,677.69, and R$29,757.69 per hectare, respectively. For the treatment without fertilizer, the average cost was R$11,947.69 per hectare and for the mineral treatment, it was R$15,013.57 per hectare. The prices of inputs and services were determined based on October 2021 in the city of Mossoró-RN. The rate of return (RR) per real invested was obtained using the relationship between gross income and total production costs of each treatment, and the profit margin (PM) obtained from the relationship between net income and gross income was expressed as a percentage.

A univariate analysis of variance for a randomized complete block design was performed to evaluate the agronomic characteristics and economic indicators of cowpea using SISVAR software (FERREIRA, 2011). A joint analysis of these variables was also performed to determine whether there was an interaction between the tested treatments and the cropping seasons. Subsequently, a regression curve fitting procedure was performed using Table Curve software (SYSTAT SOFTWARE, 2022) to estimate the behavior of each characteristic or indicator as a function of the equitable amounts of studied *M. aegyptia* and *C. procera* biomass, based on the following criteria: on the biological logic (LB) of the variable, that is, when it is found that after a certain dose of fertilizer there is no increase in the variable; on the significance of the mean square of the regression residue (QMRR); at high value of the coefficient of determination (R^2); in the significance of the parameters of the regression equation; and in the maximization of the variable. The F test was used to compare the average values between the cropping seasons, the average values of maximum agronomic or economic efficiency, the average value of the treatment fertilized with green manure, the average value of the treatment fertilized with mineral fertilizer, and the average value of the control treatment (not fertilized).

RESULTS AND DISCUSSION

Characteristics of cowpea plants and green pods

The results of the analysis of variance for the characteristics plant height, length of green pods, number of green pods per plant and productivity of cowpea green pods are shown in Table 1. Significant interactions were detected between the treatment factors of equitable biomass amounts of *M. aegyptia* and *C. procera* and cropping seasons in these cowpea characteristics.

Table 1. Mean values of plant height, green pod length, number of green pods per plant, productivity of green pods, number of green grains per pod, weight of 100 green grains, productivity of green grain and dry mass of green grain of cowpea over the growing seasons of 2020 (S_1) and 2021 (S_2) for the control treatment (T_c), for the treatment of maximum physical efficiency (MPE), for green manure treatments (T_{gm}), and for the mineral-fertilized treatment (T_{mf}).

Comparison treatments	Plant height (cm)			Green pods length (cm)		
	Cropping seasons			Cropping seasons		
	2020	2021	2020/2021	2020	2021	2020/2021
	(S_1)	(S_2)	(S_1/S_2mean)	(S_1)	(S_2)	(S_1/S_2 mean)
Control treatment (T_c)	63.06a	54.79b	58.92	20.82a	20.21a	20.52
MPE treatment	67.26a$^+$	63.66b$^+$	65.46$^+$	21.74a$^+$	21.27a$^+$	21.48$^+$
Manure treatments (T_{gm})	65.73a$^+$	61.64b$^+$	63.68$^+$	21.56a$^+$	21.07a$^+$	21.32$^+$
Mineral treatment (T_{mf})	69.51a$^+$	68.99a$^+$	69.25$^+$	22.38a$^+$	21.72b$^+$	22.05$^+$
CV (%)	3.73	5.66	4.74	2.33	2.23	2.28
	Number of green pods per plant			Productivity of green pods (t ha^{-1})		
Control treatment (T_c)	5.84a	2.91b	4.38	2.96a	2.15b	2.56
MPE treatment	7.19a$^+$	6.89a$^+$	6.93$^+$	3.72b$^+$	4.18a$^+$	3.92$^+$
Manure treatments (T_{gm})	6.97a$^+$	6.05a$^+$	6.51$^+$	3.56a$^+$	3.85a$^+$	3.71$^+$
Mineral treatment (T_{mf})	8.26a$^+$	4.81b$^+$	6.54$^+$	3.80a$^+$	3.04b$^+$	3.42$^+$
CV (%)	14.14	18.03	15.84	10.94	15.30	13.28
	Number of green grains per pod			Weight of 100 green grains (g)		
Control treatment (T_c)	9.12a	9.07a	9.10	34.08b	38.79a	36.44
MPE treatment	9.56a$^+$	9.73a$^+$	9.64$^+$	34.51b$^+$	41.90a$^+$	38.16$^+$
Manure treatments (T_{gm})	9.46a$^+$	9.59a$^+$	9.53$^+$	34.01b$^+$	41.57a$^+$	37.79$^+$
Mineral treatment (T_{mf})	10.08a$^+$	10.39a$^+$	10.23$^+$	42.52a$^+$	42.28a$^+$	42.40$^+$
CV (%)	6.15	7.80	8.03	6.16	3.98	5.04
	Productivity of green grains (t ha^{-1})			Dry mass of green grains (t ha^{-1})		
Control treatment (T_c)	2.85a	1.49b	2.17	0.523a	0.318b	0.421
MPE treatment	3. 60b$^+$	4.56a$^+$	4.03$^+$	0.713b$^+$	1.023a$^+$	0.856$^+$
Manure treatments (T_{gm})	3.48b$^+$	4.01a$^+$	3.75$^+$	0.688b$^+$	0.866a$^+$	0.777$^+$
Mineral treatment (T_{mf})	4.79a$^+$	3.44b$^+$	4.12$^+$	0.863a$^+$	0.858a$^+$	0.861$^+$
CV (%)	9.48	14.22	12.08	16.81	17.12	17.03

*Means followed by the same small letter in the row do not differ by F test at the 5% probability. $^+$Mean of manure treatments, MPE treatment or mineral treatment is significantly different from the control treatment mean by the F test at the 5% probability level.

Studying the amount of green manure within each cropping season (S) in terms of plant height, length of green pods, number of green pods per plant and productivity of green pods, an increasing behavior was observed as a function of the increase of equitable amounts of *M. aegyptia* and *C. procera* incorporated into the soil in a polynomial model for each trait, both in the first (S_1) and (S_2) cropping seasons (Figure 3).

The values of maximum physical efficiency of these characteristics were 67.26 (S_1) and 63.65 cm (S_2) in plant height, 21.79 (S_1) and 21.27 cm (S_2) in the length of green pods, 7.18 (S_1) and 6.94 (S_2) in the number of green pods per plant, and 3.73 (S_1) and 4.20 t ha^{-1} in the productivity of green cowpea pods with a green manure biomass of 59.16 (S_1) and 58.27 (S_2), 39.35 (S_1) and 50.51 (S_2), 24.90 (S_1) and 49.37 (S_2), and 29.06 (S_1) and 47.67 t ha^{-1} (S_2), respectively, decreasing the values until the last amount incorporated (Figures 3A to 3D). However, estimating the maximum physical efficiencies of these characteristics on the cropping seasons, a polynomial-increasing behavior was also observed, as a function of the increasing amounts of green manure up to the maximum values of 65.46 cm (plant height), 21.44 cm (length of green pods), 6.91 green pods per plant and 3.90 t ha^{-1} (productivity of the green pods) with amounts of green manure of 58.66, 44.01, 46.69, and 45.07 t ha^{-1}, then decreasing up to the greatest amount of tested fertilizers (Figures 3A to 3D).

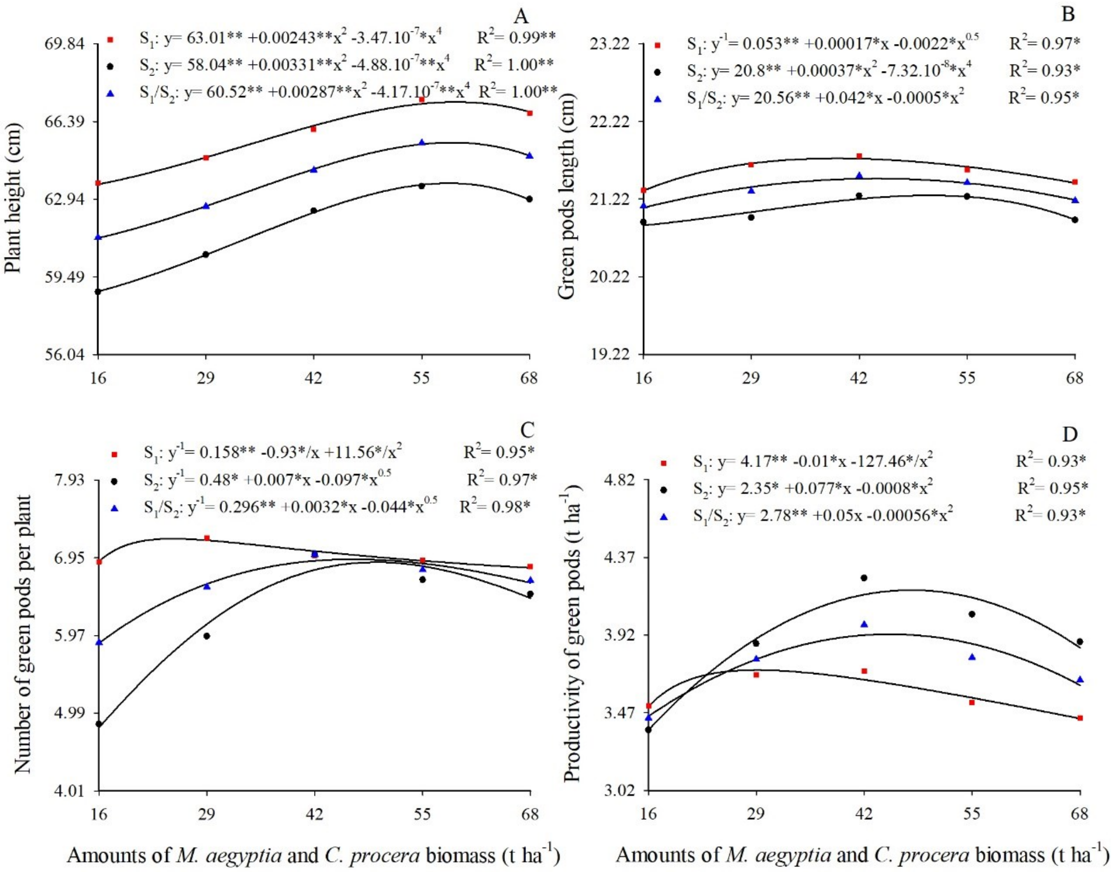

Figure 3. Plant height (A), green pod length (B), number of green pods per plant (C) and productivity of green pods (D) of cowpea as a function of equitable amounts of *M. aegyptia* and *C. procera* biomass incorporated into the soil in the 2020 (S_1) and 2021(S_2) cropping seasons.

The average values of maximum physical efficiency (MPE) of the treatments that received green manure (T_{gm}) and the mineral treatment (T_{mf}) differed from the control (T_c) in the characteristics plant height, length of green pods, number of green pods per plant and productivity of cowpea green pods (Table 1). In these characteristics, the MPE values were 1.1–1.5 times the Tc values. The cropping seasons within the MPE treatment differed in the height of plants, with S_1 outperforming S_2, and in the productivity of cowpea green pods, with S_2 outperforming S_1. In the control treatment, the average value of S_1 stood out from S_2 in plant height, number of green pods per plant and productivity of green pods. Regarding the length of green pods, the mean values for S_1 and S_2 were similar (Table 1).

The behavior of the plant and green pod characteristics of cowpea in the form of a polynomial model can be attributed to the Law of Maximum, where the excess of a nutrient in the soil provided by the equitable amounts of *M. aegyptia* and *C. procera* can have a toxic effect and/or decrease the effectiveness of other factors, resulting in a reduction in the value of these characteristics under analysis after the maximum point (ALMEIDA et al., 2015). However, another possible explanation for the behavior of these characteristics is that the due synchrony between the decomposition and mineralization of green manure added to the soil and the moment of greater nutritional demand for cowpea (FONTANÉTTI et al., 2006) provided this behavior, where these characteristics reached a maximum value and soon after began to decrease in value.

Vieira et al. (2018) studied cowpea fertilization with different doses of roostertree biomass in the same region and observed that of the cowpea pod characteristics evaluated, only the dry mass of green pods had the same behavior in terms of the polynomial model obtained in this work; that is, the other characteristics did not have a decrease in values after their maximum points. Regarding the number of pods per plant and the productivity of green pods, the values were similar to those recorded in this study. Presumably, this difference in the behavior of these characteristics is due to the cultivar, nutritional availability and water reserve in the soil, among other factors. In this work, the cultivar was semi-erect, while in the authors' work, the cultivar was erect.

Characteristics of cowpea green grains

Analyzing the amount of green manure within each cropping season (S) in the characteristics of the cowpea green grain, number of green grains per pod, weight of 100 green grains, productivity of green grain and dry mass of green grain, an increasing behavior was observed as a function of the increase in equitable amounts of *M. aegyptia* and *C. procera* incorporated into the soil in a polynomial model for each trait, both in the first (S_1) and second (S_2) cropping seasons (Figure 4).

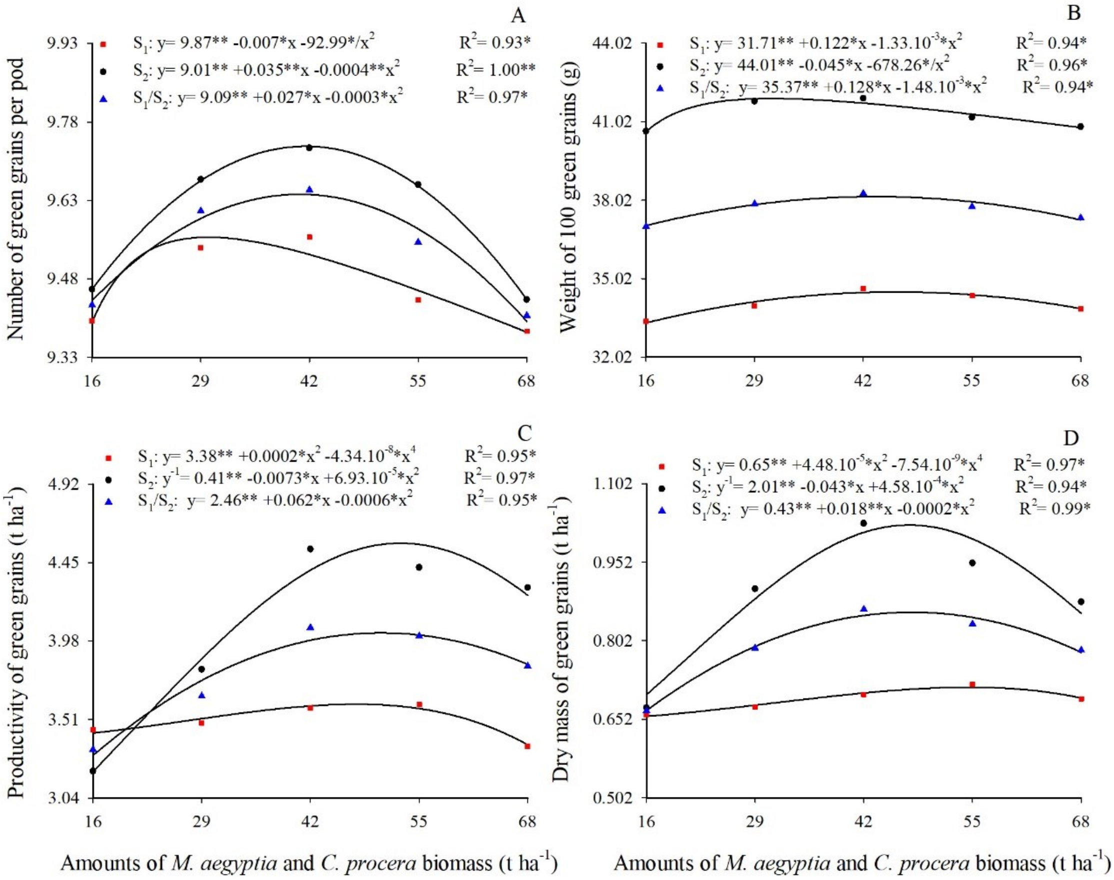

Figure 4. Number of green grains per pod (A), weight of 100 green grains (B), productivity of green grain (C) and dry mass of green grain (D) of cowpea as a function of equitable biomass amounts of *M. aegyptia* and *C procera* incorporated into the soil in the 2020 and 2021 cropping seasons.

The maximum physical efficiency values of these characteristics were 9.56 (S_1) and 9.77 (S_2) grains per green pod, 34.51 (S_1) and 41.91 g (S_2) for the weight of 100 green grains, 3.61 (S_1) and 4.59 t ha^{-1} (S_2) for the productivity of green grains, and 0.713 (S_1) and 1.023 t ha^{-1} for dry mass of green cowpea grains, in the green manures amounts of 29.88 (S_1) and 41.54 (S_2), 45.94 (S_1) and 31.09 (S_2), 47.45 (S_1) and 52.76 (S_2), and 54.52 (S_1) and 47.47 t ha^{-1} (S_2), respectively, decreasing the values until the last incorporated amount (Figures 4A to 4D).

However, estimating the maximum physical efficiencies of these characteristics on the cropping seasons, a polynomial-increasing behavior was also observed as a function of the increasing amounts of green manures up to the maximum values. These maximum values were 9.69 for the number of green grains per pod, 38.14 g for the weight of 100 green grains, 4.06 t ha^{-1} for the productivity of green grains, and 0.830 t ha^{-1} for the dry mass of green grains in green manure amounts of 40.83, 43.43, 50.48 and 47.72 t ha^{-1}, respectively, then decreasing to the greatest amount of the tested manure (Figures 4A to 4D). These values were very close to those obtained by Vieira et al. (2018), who studied cowpea fertilization with doses of roostertree biomass in the same region and recorded 7 green grains per pod, 39.12 g as the weight of 100 cowpea green grains, 3.05 t ha^{-1} as the productivity of green grains and 1.24 t ha^{-1} as the dry mass of green grains. These differences are due to the planted cowpea cultivar; in the work by Vieira et al. (2018), they used an upright cowpea cultivar, while in this research, the authors used a semi-upright cowpea cultivar.

The average values of maximum physical efficiency (MPE) of the treatments that received green manure (T_{gm}) and mineral treatment (T_{mf}) differed from the control (T_c) in cowpea green grain characteristics (Table 1). In these characteristics, the MPE values were about 1.05 to 2.03 times the T_c values. The cropping seasons in the MPE treatment differed in the weight of 100 green grains and in the productivity and dry mass of green grains with S_2 detaching from S_1. For the number of green grains per pod, no differences were recorded between the mean values of S_1 and S_2. In the control treatment, the average value of S_1 stood out from S_2 in the productivity and dry mass of green grains. In the weight of 100 green grains, S_2 outperformed S_1, and in the number of green grains per pod, the mean values of the S_1 and S_2 seasons were similar (Table 1).

The behavior of these characteristics of cowpea green grain was in the form of a polynomial model due to the greater availability of nutrients released by increasing the equitable amounts of *M. aegyptia* and *C. procera* added to the soil, thus increasing the weight and number of green grains per pod, its productivity and dry mass per area. In addition, this behavior also depends on the synchrony between the release and absorption of nutrients by cowpea plants (SILVA et al., 2021b).

The amounts of macronutrients contained in the tested green manures met the nutritional needs of cowpea plants. According to Taiz et al. (2017), the concentration of nitrogen favors the growth and development of plants, thus increasing the weight and number of green grains per pod. Potassium greatly influences the photosynthesis of the plant, and phosphorus affects the formation of fruit and seeds, directly influencing the productivity and weight of green grains, as well as the quality of the harvested products.

Cowpea economic indicators

The results of the analysis of variance for the economic indicators of cowpea, gross income, net income, rate of return and profit margin are presented in Table 2. Significant interactions between the equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil and cropping seasons were recorded in the cowpea economic indicators (Table 2).

Table 2. Mean values of gross income, net income, rate of return and profit margin of cowpea over the 2020 and 2021 growing seasons for the control treatment (T_c), for the treatment of maximum economic efficiency (MEE), for green manure treatments (T_{gm}), and for the mineral-fertilized treatment (T_{mf}).

Comparison treatments	Gross income (R$ ha^{-1})			Net income (R$ ha^{-1})		
	Growing seasons			Growing seasons		
	2020	2021	2020/2021	2020	2021	2020/2021
	(S_1)	(S_2)	(S_1/S_2mean)	(S_1)	(S_2)	(S_1/S_2 mean)
Control (T_c)	13177.60a	13455.10a	13316.35	1429.90a	1507.40a	1468.65
MEE treatment	28048.59b$^+$	31834.09a$^+$	29790.03$^+$	4124.33b$^+$	7681.58a$^+$	5806.78$^+$
Manure treatments (T_{gm})	26179.41b$^+$	28811.69a$^+$	27495.55$^+$	3107.71b$^+$	5688.00a$^+$	4397.86$^+$
Mineral treatment (T_{mf})	24610.20a$^+$	23694.40a$^+$	24152.30$^+$	9596.70a$^+$	8680.90a$^+$	9138.80$^+$
CV (%)	4.65	3.84	4.24	29.13	18.56	22.58
	Rate of return			Profit margin (%)		
Control (T_c)	1. 10a	1.12a	1.11	9.24a	11.14a	10.19
MEE treatment	1.17b$^+$	1.32a$^+$	1.25$^+$	15.48b$^+$	25.12a$^+$	19.88$^+$
Manure treatments (T_{gm})	1.15b$^+$	1.25a$^+$	1.20$^+$	11.93b$^+$	19.77a$^+$	15.85$^+$
Mineral treatment (T_{mf})	1.64a$^+$	1.58a$^+$	1.61$^+$	38.98a$^+$	36.51a$^+$	37.75$^+$
CV (%)	4.93	4.06	4.50	24.74	13.53	18.49

*Means followed by the same small letter in the row do not differ by F test at the 5% probability. $^+$Mean of manure treatments, MPE treatment or mineral treatment is significantly different from the control treatment mean by the F test at the 5% probability level.

Studying the amounts of green manures within each cropping season (S), an increase in the gross income, net income, rate of return and profit margin was observed both in the first (S_1) and second (S_2) growing seasons as a function of increasing equitable biomass amounts of *M. aegyptia* and *C. procera* added to the soil in a polynomial model (Figure 5). The maximum values were R$28,026.87 ($S_1$) and R$31,848.44 ha^{-1} (S_2) in gross income, R$4159.16 ($S_1$) and R$7627.81 ha^{-1} (S_2) in net income, 1.18 (S_1) and 1.35 (S_2) reals for each real invested in the rate of return, and 15.44 (S_1) and 25.13% (S_2) in the profit margin for green manure biomass values of of 62.26 (S_1) and 54.51 (S_2), 35.94 (S_1) and 40.91 (S_2), 38.47 (S_1) and 36.58 (S_2), as well as 37.18 (S_1) and 40.36 t ha^{-1} (S_2), respectively, decreasing the values until the last amount incorporated (Figures 5A, 5B , 5C and 5D).

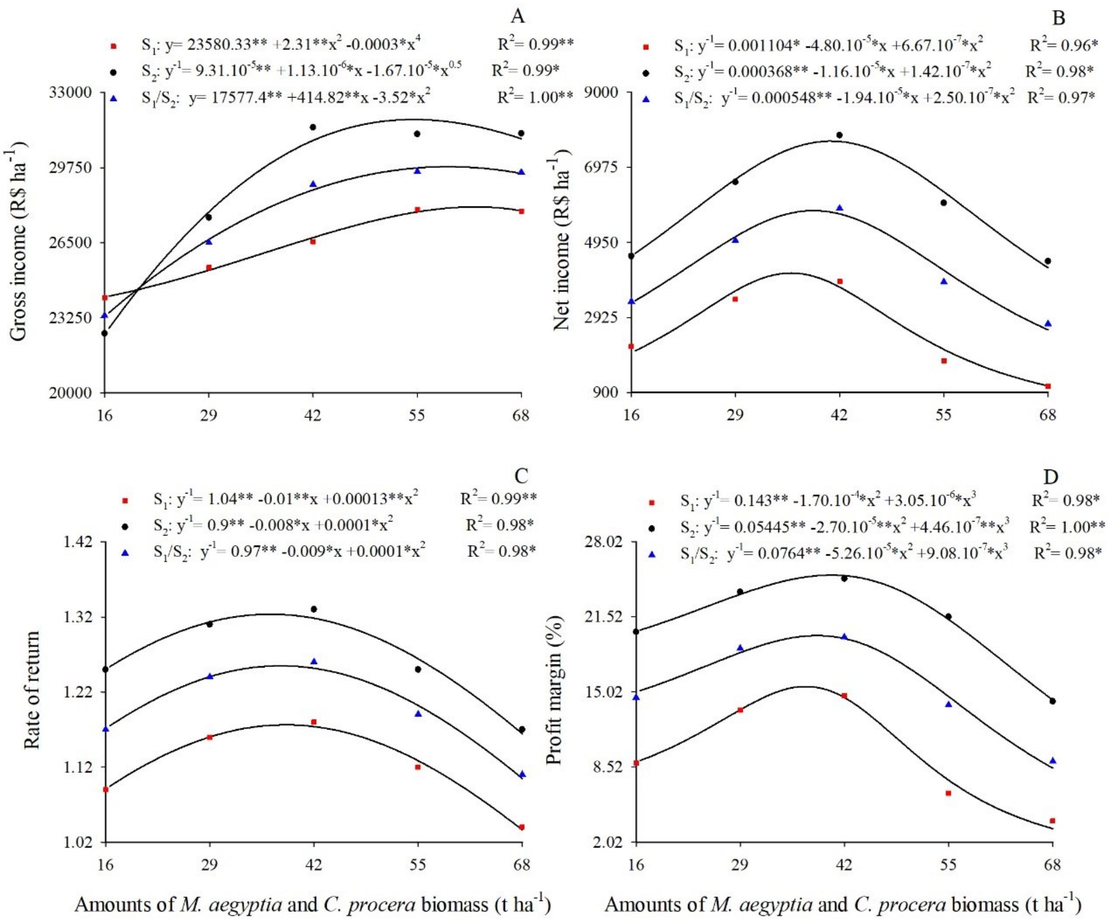

Figure 5. Gross income, net income, rate of return and profit margin of cowpea as a function of equitable biomass amounts of *M. aegyptia* and *C. procera* incorporated into the soil in the 2020 and 2021 growing seasons.

Estimating the maximum economic efficiencies (MEE) of these indicators over the cropping seasons, polynomial behavior was also recorded as a function of the amount of green manure (Figure 5). The maximum values were R$29,798.67 and R$5826.12 ha^{-1} for gross income and net income, respectively, and 1.29 and 19.90% for the rate of return and profit margin, respectively, for a green manure biomass of 58.88, 38.74, 37.85 and 38.60 t ha^{-1}, respectively, then decreasing up to the greatest amount of the tested fertilizers (Figures 5A, 5B, 5C and 5D).

The average values of maximum economic efficiency (MEE) for treatments that received green manure (T_{gm}) and mineral treatment (T_{mf}) differed from the control (T_c) in all cowpea economic indicators (Table 2). The cropping seasons within the MEE treatment differed in all economic indicators, with an emphasis on the second cropping season. In the control treatment, there was no difference between S_1 and S_2 in all evaluated indicators (Table 2).

These ascending responses of the economic indicators evaluated in cowpea with a decrease after the maximum point in the form of a polynomial model as a function of the equitable biomass amounts of *M. aegyptia* and *C. procera* were due to the good response of cowpea to incorporating green manure, where its performance in terms of production was translated into economic terms. According to Graham and Haynes (2006), green manure is known to improve fertility, increase organic matter content, decrease erosion rates, increase the water retention in soil, increase the microbiota activity of the soil, increase soil nutrient availability and reduce the amount of invasive plants.

CONCLUSIONS

The maximum optimized physical (agronomic) efficiencies of the production of pods and cowpea green grain were reached at a green pod productivity yield of 3.90 t ha^{-1} and green grain productivity of 4.06 t ha^{-1}, with 45.07 and 50.48 t ha^{-1} of *Merremia aegyptia* and *Calotropis procera* biomass, respectively, incorporated into the soil. The maximum economic efficiency of the production of green grains of cowpea was reached at a net income of R$5,826.12 ha^{-1} and at a rate of return of 1.29 reals for each real invested with application to the soil of 38.74 and 37.85 t ha^{-1} of tested green manure biomass. The use of *M. aegyptia* and *C. procera* biomass as green manure is a viable technology for cowpea monoculture producers in semi-arid environments.

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