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Scientific Article

Agro-economic optimization of coriander under biomass mixtures of mixed organic fertilizers in semi-arid environment

Otimização agroeconômica do coentro sob misturas de biomassa de fertilizantes orgânicos mistos em ambiente semiárido

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ABSTRACT - The objective of this study was to evaluate the agronomic and economic performance of coriander using equitable biomass mixtures of dry *Merremia aegyptia*, *Calotropis procera*, and goat manure across two cropping cycles conducted under semiarid environment conditions in the Brazilian Northeast. The experiment was conducted under open-field conditions at the Rafael Fernandes Experimental Farm, in Mossoró, using a randomized complete block design with five treatments and five replications. The treatments consisted of equitable biomass mixtures of *Merremia aegyptia*, *Calotropis procera*, and goat manure at rates of 24, 42, 60, 78, and 96 t ha^{-1} on a dry weight basis. In each block, two additional control treatments were included: one without fertilization and another with mineral fertilization. The coriander cultivar used was 'Verdão'. In the interaction between the two coriander cropping cycles, maximum agronomic efficiency was achieved with a total incorporation of 82.29 t ha^{-1} of the equitable organic fertilizer mixture, yielding a green biomass of 2.64 t ha^{-1}, whereas the incorporation of 81.74 t ha^{-1} yielded 2.61 bunches m^{-2}. The maximum economic efficiency resulting from the interaction between the two coriander cropping cycles was achieved with a total incorporation of 73.63 t ha^{-1} of the equitable organic fertilizer mixture for a net income of BRL 41,482.33 ha^{-1}, whereas the incorporation of 63.54 t ha^{-1} resulted in a rate of return of BRL 1.98 per real invested, and the incorporation of 54.7 t ha^{-1} yielded a profit margin of 50.08%.

Keywords: *Coriandrum sativum*. *Calotropis procera*. *Merremia aegyptia*. Organic fertilization. Semiarid region. Economic viability.

RESUMO – O objetivo deste trabalho foi avaliar o desempenho agronômico e econômico do coentro utilizando misturas equitativas de biomassa seca de *Merremia aegyptia*, *Calotropis procera* e esterco caprino, em dois ciclos de cultivo, conduzidos em condições de ambiente semiárido no Nordestido brasileiro. O experimento foi conduzido em campo aberto na Fazenda Experimental Rafael Fernandes, em Mossoró, com delineamento em blocos casualizados, cinco tratamentos e cinco repetições. Os tratamentos consistiram em misturas equitativas de biomassa de *Merremia aegyptia*, *Calotropis procera* e esterco caprino, nas quantidades de 24, 42, 60, 78 e 96 t ha^{-1} em base seca. Em cada bloco, foram adicionados dois tratamentos adicionais: um sem fertilização e outro com fertilização mineral. A cultivar de coentro utilizada foi a Verdão. Na interação entre os dois cultivos de coentro, a máxima eficiência agronômica foi alcançada com incorporação total de 82,29 t ha^{-1} da mistura equitativa dos fertilizantes orgânicos, resultando na produtividade de massa verde de 2,64 t ha^{-1}, enquanto a incorporação de 81,74 t ha^{-1} proporcionou 2,61 maços por m^2. A máxima eficiência econômica decorrente da interação entre os dois cultivos de coentro foi alcançada com a incorporação total de 73,63 t ha^{-1} da mistura equitativa dos fertilizantes orgânicos para a renda líquida de R$ 41.482,33 ha^{-1}, enquanto a incorporação de 63,54 t ha^{-1} resultou em uma taxa de retorno de R$ 1,98 para cada real investido e a incorporação de 54,7 t ha^{-1} proporcionol uma margem de lucro de 50,08%.

Palavras-chave: *Coriandrum sativum*. *Calotropis procera*. *Merremia aegyptia*. Adubação orgânica. Semiárido. Viabilidade econômica.

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INTRODUCTION

Coriander (*Coriandrum sativum* L.) is a vegetable native to the Mediterranean region, cultivated and consumed in different parts of the world. In addition to its culinary use, it has great medicinal and nutritional value, with well-documented functional and bioactive properties on a global scale, resulting in growing scientific interest in the species (LIU et al., 2024; SÁNCHEZ-NAVARRO et al., 2023). In Brazil, it stands out for its economic and social importance in the North and Northeast regions, where the production system is marked by a strong presence of family farming, income generation, food security, and adaptation to the climatic and soil conditions of the regions. Production meets both local and regional consumption, where the herb is an essential culinary ingredient, and seed production (CHIANCA; OLIVEIRA, 2022).

Coriander cultivation is predominantly carried out under conventional systems, with intensive use of chemical fertilizers. This practice, although efficient in the short term, has been associated with soil degradation, environmental contamination, and economic dependence on resources external to the property (SILVA et al., 2024). In contrast, the demand for healthier and more environmentally sustainable foods has increased, driving the adoption of organic

fertilizers and green manure, capable of reducing the use of chemical inputs and improving the environmental performance of production systems (KHAN; ALEINIKOVIENÉ; BUTKEVICIENE, 2024).

In the Brazilian Semi-Arid region, where limited external inputs and climatic restrictions pose challenges to agricultural sustainability, practices based on resources available on the farm are gaining relevance (EZZAT et al., 2025). The use of biomass from spontaneous plants of the Caatinga biome and animal manure has shown potential to promote improved soil fertility, increasing crop productivity and nutrient use efficiency (FERREIRA et al., 2022). Species such as hairy woodrose [*Merremia aegyptia* (L.) Urb.] and roostertree [*Calotropis procera* (Ait.) R. Br.] exhibit high adaptability to the biome and biomass production with a balanced nutritional contribution, which makes them suitable for use as green manures (FERREIRA et al., 2022).

Among fertilizers of animal origin, bovine manure is the most common due to its availability on farms. However, recent evidence indicates that goat manure may have a higher concentration of nutrients, favoring the cultivation of vegetables in poor soils (SANTOS et al., 2020). Despite the advancement in the use of bio-inputs, studies that evaluate, in an integrated way, the physical and agroeconomic efficiency of the combined use of green manures and goat manure in agricultural systems in the Semi-arid region, simultaneously considering aspects of productivity, profitability, nutrient cycling, and reduction of dependence on external inputs, are scarce (EZZAT et al., 2025; KHAN; ALEINIKOVIENÉ; BUTKEVICIENE, 2024).

Given this, it is hypothesized that the integration of these organic sources improves the productive and economic performance of coriander, strengthening the sustainability of the production system. Thus, this work aimed to evaluate the agroeconomic efficiency of coriander grown under different equitable amounts of biomass from mixed organic fertilizers (*M. aegyptia*, *C. procera* and goat manure) in two cropping periods in a semi-arid environment.

MATERIALS AND METHODS

Description and geographical context of the experimental areas

The experiments were conducted over two growing cycles: the first cycle ran from July 31 to September 19, 2025 (Crop Cycle 1 - C1), and the second ran from August 14 to October 3, 2025 (Crop Cycle 2 - C2).

Both trials were conducted at the Rafael Fernandes Experimental Farm of the Federal Rural University of the Semi-Arid Region (UFERSA), located in the Lagoinha district, approximately 20 km from the municipality of Mossoró, Rio Grande do Norte, Brazil. The experimental area is located at 5°03′37″ S latitude and 37°23′50″ W longitude, at an altitude of 80 m above sea level.

According to the Köppen–Geiger climate classification, the region is classified as BShw, characterized by a hot and dry climate. Two well-defined seasons are observed: a dry season, generally extending from June to January, and a rainy season, from February to May (BECK et al., 2018). The average climatic data recorded during the experimental cycles are presented in Table 1 (LABIMC, 2025).

Average daily temperature and relative humidity during the coriander crop cycles C1 and C2 are presented in Figure 1.

Table 1. Averages of climatic variables recorded during the two coriander crop cycles (C1 and C2).

Cropping periods	Temperature (ºC)			Relative humidity (%)	Solar radiation (MJ m^{-2})	Reference evapotranspiration (mm day^{-1})
	Minimum	Average	Maximum			
C1	21.7	27.8	35.4	54.0	17.7	5.2
C2	21.9	28.1	35.8	52.3	18.5	5.6

Source: LAMBIC, 2025. Values represent the mean of the daily measurements recorded during each cropping cycle.

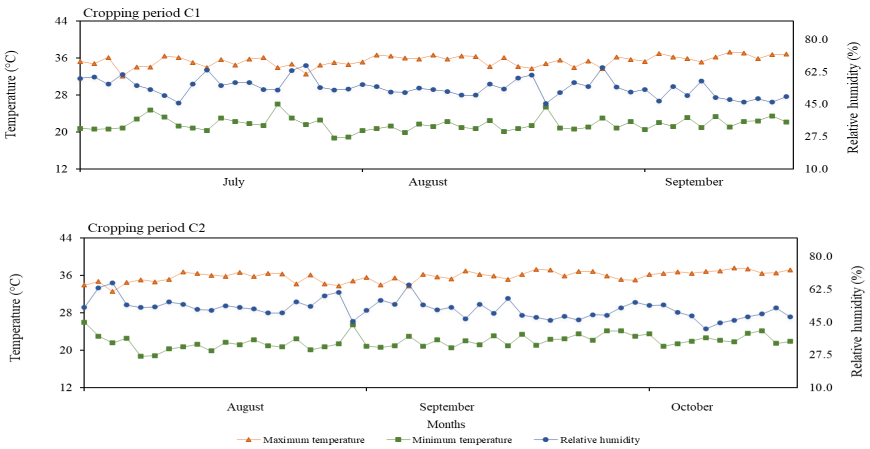


Figure 1. Data on daily averages of temperatures and air relative humidity during coriander cropping cycles C1 and C2.

The soils of the experimental areas are classified as *Latossolo Vermelho Amarelo* (Oxisol) with a sandy loam texture, according to Santos et al. (2018). Before trial establishment, composite disturbed soil samples were collected at a depth of 0 - 20 cm (representing the effective root zone) for chemical characterization and fertility analysis, according to the methodology described by Teixeira et al. (2017).

The chemical analyses revealed the following concentrations: phosphorus (P) at 16.82 mg dm^{-3}; potassium (K) at 0.4 $cmol_c$ dm^{-3}; calcium (Ca) at 6.92 $cmol_c$ dm^{-3}; magnesium (Mg) at 1.07 $cmol_c$ dm^{-3}; sodium (Na) at 0.042 $cmol_c$ dm^{-3}; organic matter (OM) at 14.70 g dm^{-3}; organic carbon (OC) at 4.55 g kg^{-1}; manganese (Mn) at 11.31 mg dm^{-3}; zinc (Zn) at 5.51 mg dm^{-3}; iron (Fe) at 4.90 mg dm^{-3}; and copper (Cu) at 4.09 mg dm^{-3}.

Experimental design and treatments

The study was arranged in a randomized complete block design, comprising five treatments with five replications. The treatments were defined by increasing and equivalent rates of *M. aegyptia* biomass, *C. procera* biomass, and goat manure, applied at 24, 42, 60, 78, and 96 t ha^{-1} on a dry matter basis. Within each block, two additional treatments were included: an unfertilized control (absolute control) and another treatment with mineral fertilization, both used to contrast with the treatment that achieved maximum agroeconomic efficiency.

Mineral fertilization treatment was carried out according to the recommendation of Trani et al. (2022) for coriander cultivation, with the application of N, P_2O_5, and K_2O as basal seven days before planting, in quantities of 40, 320, and 60 kg ha^{-1}, respectively, and in topdressing with 40, 20, and 40 kg ha^{-1} of N, P_2O_5, and K_2O applied 15 days after germination, between the rows in small furrows covered with soil to avoid nitrogen losses through volatilization. The following commercial single fertilizers were used as NPK sources: Urea: 45% N, Single Superphosphate (SSP): 18% P_2O_5, and Potassium Chloride (KCl): 58% K_2O.

Each experimental plot in the open field occupied a total area of 1.44 m², of which 0.80 m² corresponded to the harvest area. Plots were composed of six rows containing 24 coriander plants each, arranged at a spacing of 0.20 m × 0.05 m, as described by Andrade Filho et al. (2020). This configuration resulted in an estimated plant density of approximately 1,000,000 plants per hectare (Figure 2).

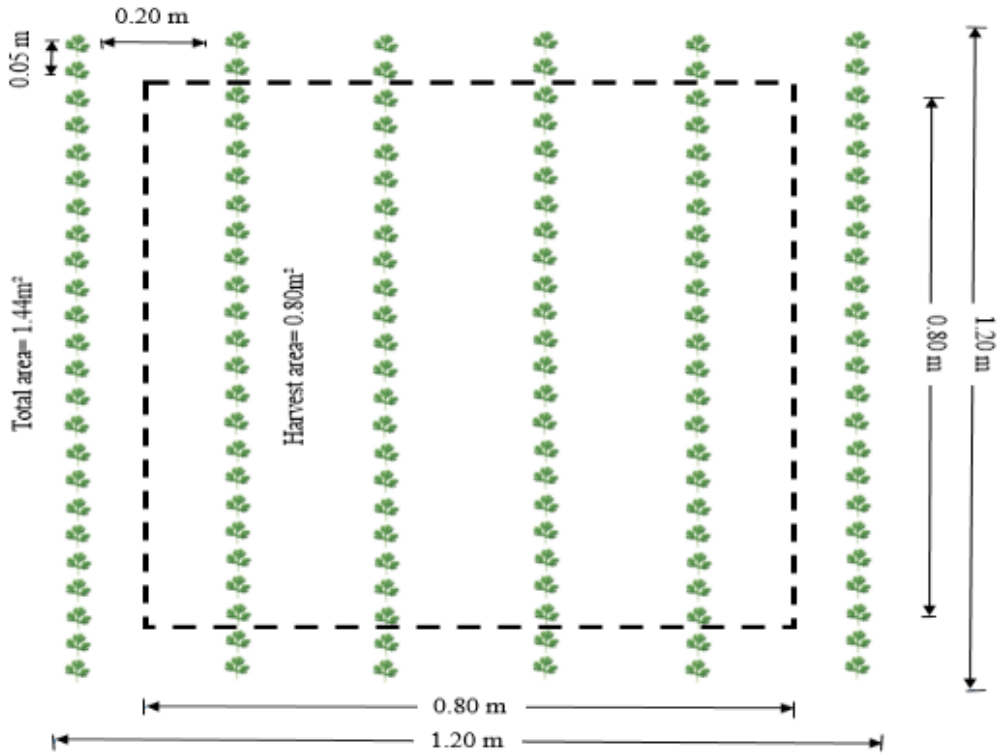


Figure 2. Schematic representation of a coriander monocropping plot established at a spacing of 0.20 m × 0.05 m.

Installation and conducting the experiments

The green manures *M. aegyptia* and *C. procera* were collected from spontaneous vegetation in urban and rural surroundings of the municipality of Mossoró, RN, prior to the onset of flowering, a period associated with greater accumulation of energy reserves in plant fresh matter. After harvesting, the plant material was mechanically chopped using a forage shredder, producing fragments approximately 2-3 cm in length. The biomass was subsequently sun-dried until reaching a moisture content close to 10%.

Goat manure was obtained from the Federal Institute of Education, Science and Technology of Rio Grande do Norte (IFRN), Apodi Campus. The manure originated from Anglo-Nubian goats aged between one and three years, managed under a semi-intensive system and fed with corn and sorghum

silage, concentrate, and pasture forage.

Samples of *M. aegyptia*, *C. procera*, and goat manure were taken and sent to the Rio Grande do Norte Agricultural Research Company (EMPARN) for determination of nutrient contents, and the following results were obtained: N= 1.73; 1.87; 3.02%; P= 3.04; 1.84; 3.93 g kg^{-1}; K= 45.29; 39.85; 3.55 g kg^{-1}; Ca= 4.95; 1.95; 14.70 g kg^{-1}; Mg= 2.50; 4.62; 5.75 g kg^{-1}; Na= 5.44; 12.50; 1.87 g kg^{-1}; Zn= 13; 11; 95 mg kg^{-1}; Cu= 8; 6; 65 mg kg^{-1}; Fe = 292; 110; 1312 mg kg^{-1}; Mn = 22; 44; 300 mg kg^{-1}; OC = 36.67; 33.17; 36.28% and C:N ratio = 21:1; 17:1; 11:1, respectively.

Soil preparation in the experimental areas involved mechanical plowing followed by harrowing. Seedbeds were then formed using a backhoe. *M. aegyptia* biomass, *C. procera* biomass, and goat manure were incorporated into the soil in equivalent proportions at a depth of 0-20 cm using hoes. Plant biomasses were incorporated twenty days before sowing, whereas goat manure was incorporated five days prior to sowing.

The coriander cultivar used was Verdão, which is recommended for the Northeast region due to its tolerance to high temperatures and its vigorous vegetative growth. This cultivar is characterized by dark green leaves, thick stems, a strong and distinctive aroma and flavor, and a short growth period, typically ranging from 30 to 40 days. Sowing for cropping cycles 1 (C1) was performed on August 19, 2025, and for cropping cycles 2 (C2) on September 3, 2025. In both cycles, sowing was carried out directly in planting holes 3 cm deep, with four to five seeds placed in each hole.

Thinning was conducted in two steps: seven days after emergence, three plants were retained per hole, and at fifteen days, thinning was completed by maintaining a single plant per hole. Irrigation was applied daily using a microsprinkler system, with an application depth of approximately 8 mm day^{-1}, adopted based on the irrigation management described by Ferreira et al. (2022) under experimental conditions similar to those of the present study. The depth was maintained daily throughout the crop cycles. Throughout the experimental cycles, cultural practices such as manual weed control and soil surface scarification were implemented. Harvesting in both cropping cycles was carried out 30 days after sowing.

Evaluated Characteristics

The evaluation of the agronomic characteristics of coriander was carried out based on a sample of 20 plants, randomly harvested from the usable are of each experimental plot. The characteristics analyzed were: plant height (cm), measured from ground level to the tip of the highest leaves; number of stems per plant; leaf/stem ratio, obtained from the ratio between the fresh mass of the leaves and the fresh mass of the stems. In addition, shoot dry mass was determined by drying in a forced-air oven at 65 °C until constant weight was reached, with the values expressed in t ha^{-1}. Shoot green mass yield was calculated from the fresh mass of the plants in the harvest area and expressed in t ha^{-1}. Finally, the number of bunches per m^2 was determined based on the number of 100 g bunches obtained from the green mass yield.

The economic indicators of coriander were also evaluated, measured from gross income, net income, rate of return, and profit margin. Gross income, expressed in BRL ha^{-1}, was determined by the product of the green mass yield in each treatment and the value paid to the producer at the time of harvest of C1 and C2 (BRL 17.00 per kilogram). Net income, also expressed in BRL ha^{-1}, was calculated by subtracting production costs from gross income, which included expenses for inputs and services applied in each treatment. Input, production, and service costs were calculated considering the regional prices prevailing during the execution of the experiments. The rate of return on investment was determined by the ratio between gross income and production costs, while the profit margin was obtained from the relationship between net income and gross income, expressed as a percentage.

Statistical analysis

Data obtained for each evaluated trait were subjected to analysis of variance using SAS software (SAS, 2015). Homogeneity of variances between the cropping cycles was assessed by the ratio between the largest and smallest residual mean squares from the individual experiments, with acceptable values being lower than seven, as proposed by Pimentel-Gomes (2009).

After confirming variance homogeneity, a combined analysis was carried out for each trait or indicator to verify the presence or absence of interaction between the applied treatments and the coriander cropping cycles. Regression analyses were then performed using Table Curve 2D software (SYSTAT Software, 2022) to describe the response of each variable as a function of the applied amounts of *M. aegyptia* biomass, *C. procera* biomass, and goat manure. Comparisons between cropping cycles were conducted using the F-test, considering the mean values corresponding to maximum agronomic or economic efficiency, the mean of the organic fertilizer treatments, the mean of the mineral fertilization treatment, and the mean of the unfertilized control.

Polynomial regression models were fitted for each agronomic and economic variable of coriander. Model selection was based on the following criteria: variable with biological logic (BL) in behavior (i.e., when it is verified that after a certain quantity of the tested fertilizers there is no further increase in the variable); significance of the mean square of the regression (RMS); high value of the coefficient of determination (R^2); significance of the parameters of the regression equation; and maximization of the value of the evaluated variable.

RESULTS AND DISCUSSION

Agronomic characteristics of coriander

The agronomic evaluation of coriander (including plant height, leaf number per plant, leaf-to-stem ratio, bunch density per m^2, green biomass yield, and shoot dry mass) showed distinct responses across the cropping periods (Table 2). The statistical analysis indicated significant interactions between the applied quantities of mixed organic fertilizer biomass and the cultivation cycles, demonstrating that the performance of the crop varied according to both factors.

Table 2. Mean values obtained for the control treatment (T_{wf}), the treatment corresponding to maximum physical efficiency (MPE), and the mixed organic fertilizer treatments (T_{mof}), and the mineral fertilizer treatment (T_{mf}). The variables assessed were plant height, number of stems per plant, leaf/stem ratio, number of bunches per square meter, green mass yield, and shoot dry mass for the two cropping cycles, C1 and C2.

Comparison of treatments	Plant height (cm)			Number of stems per plant		
	C1	C2	C1-C2 (mean)	C1	C2	C1-C2 (mean)
Control (without fertilization, T_{wf})	4.99bA	4.42cA	4.71	3.73bB	3.94bA	3.84
MPE Treatment	11.29aA	11.43aA	11.33^{+}	5.59aB	6.73aA	6.17^{+}
Mixed organic fertilizer treatments (T_{mof})	10.51aA	10.55aA	10.53^{+}	5.38aB	5.80aA	5.59^{+}
Mineral treatment (T_{mf})	6.10bA	6.30bA	6.20^{+}	3.97bB	4.02bA	3.99
CV (%)	7.20	3.85	5.78	9.26	6.77	8.03
	Leaf/stem ratio			Number of bunches per m²		
Control (without fertilization, T_{wf})	1.99aA	1.89aA	1.95	0.31bB	0.37cA	0.34
MPE Treatment	1.48bA	1.69bA	1.57^{+}	2.56aB	2.59aA	2.61^{+}
Mixed organic fertilizer treatments (T_{mof})	1.35bA	1.47bA	1.41^{+}	2.12aB	2.19aA	2.16^{+}
Mineral treatment (T_{mf})	1.37bA	1.0cA	1.18^{+}	0.35bB	0.75bA	0.55^{+}
CV (%)	9.08	2.36	6.60	6.69	5.93	6.29
	Green mass yield (t ha^{-1})			Shoot dry mass (t ha^{-1})		
Control (without fertilization, T_{wf})	0.31bB	0.37cA	0.34	0.05bB	0.09bA	0.05
MPE Treatment	2.58aB	2.62aA	2.64^{+}	0.40aA	0.36aB	0.38^{+}
Mixed organic fertilizer treatments (T_{mof})	2.12aB	2.20aA	2.16^{+}	0.35aA	0.31aB	0.33^{+}
Mineral treatment (T_{mf})	0.35bB	0.75bA	0.55^{+}	0.10bA	0.05bB	0.10
CV (%)	6.63	5.92	6.26	14.16	7.16	11.65

*Means followed by the same lowercase letter within columns and uppercase within rows do not differ statistically from each other by F-test at a 5% probability level. $^{+}$Means of the treatments with mixed organic fertilizer, the MPE treatment, or the mineral fertilizer treatment are significantly different from the mean of the control treatment, according to the F-test at a 5% probability level.

The treatments that achieved maximum physical efficiency (MPE), both under mixed organic fertilization and under mineral fertilization (T_{mf}), showed agronomic responses that consistently exceeded those of the control treatment (T_{wf}) across the two cropping cycles. The MPE values were 2.41, 1.61, 7.65, 7.76, and 7.60 times higher than those of T_{wf} for plant height, number of leaves per plant, bunch density per m², green biomass yield, and shoot dry mass, respectively. In contrast, the leaf/stem ratio of the control was 1.24 times greater than the average MPE value, indicating that nutrient limitation favored disproportionate stem elongation.

When the mixed organic fertilizer treatments were compared within each cropping cycles, increases in the number of stems per plant, number of bunches per m², and green mass yield were verified in C2, while shoot dry mass was greater in C1. For the remaining traits, no statistical differences were detected between cycles within the organic fertilization treatments.

Analysis of the doses of mixed organic fertilizers within each cropping cycles revealed a polynomial response pattern: increases in fertilizer biomass led to progressive gains up to an optimal point, after which the variables declined (Figures 3A, 3B, 3C, 3D, 3E and 3F). The maximum physical efficiency values reached 11.29 (C1) and 11.43 cm (C2) for plant height, 5.59 (C1) and 6.73 (C2) stems per plant, 2.56 (C1) and 2.59 (C2) bunches per m², 2.58 (C1) and 2.62 (C2) t ha^{-1} of green mass, and 0.40 (C1) and 0.36 (C2) t ha^{-1} of shoot dry mass. These maximum values were obtained with applications of 67.94 (C1) and 76.76 (C2), 84.03 (C1) and 77.40 (C2), 84.04 (C1) and 82.63 (C2), 87.81 (C1) and 82.28 (C2), and 68.85 (C1) and 80.82 (C2) t ha^{-1} of an equal-parts mixture of *M. aegyptia*, *C. procera*, and goat manure, respectively (Figures 3A, 3B, 3C, 3D, 3E and 3F).

Considering the pooled analysis of MPE across cropping cycles (C1 and C2), the estimated optimal responses were 11.33 cm for plant height, 6.17 stems per plant, a leaf/stem ratio of 1.57, 2.61 bunches per m², 2.64 t ha^{-1} of green biomass, and 0.38 t ha^{-1} of shoot dry mass. These values corresponded to total biomass inputs of 72.33, 78.52, 74.17, 81.74, 82.29, and 75.84 t ha^{-1} obtained through the incorporation of equal amounts of the three organic fertilizers of *M. aegyptia*, *C. procera*, and goat manure, respectively.

Beyond these optimal rates, a decline in agronomic responses was observed, reinforcing the polynomial model and indicating that excessive biomass incorporation does not enhance productivity and may impair crop performance.

The results obtained demonstrate that mixed organic fertilizers (*M. aegyptia*, *C. procera*, and goat manure) promoted significant increases in coriander growth and yield, with a growing polynomial behavior up to a maximum point of nutrient supply. This behavior is likely determined by the mineralization dynamics of organic materials and the synchronized availability of nutrients throughout the crop cycle. Similar patterns were described by Ferreira et al. (2022), who observed the agronomic potential of spontaneous species as a source of nutrients and their positive effects on coriander productivity.

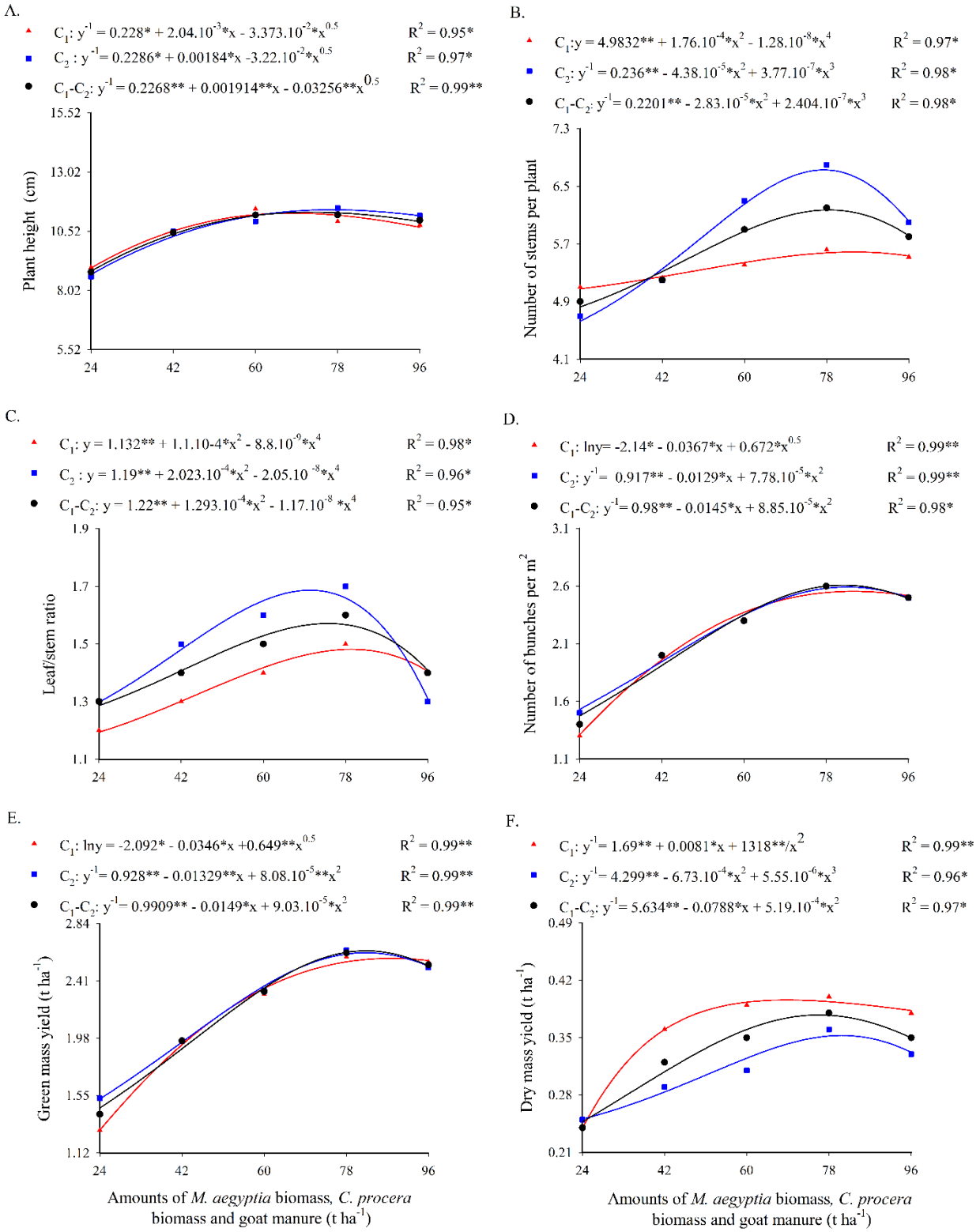


Figure 3. Plant height (A), number of stems per plant (B), leaf/stem ratio (C), number of bunches per m^2 (D), green mass yield (E) and shoot dry mass yield (F) as a function of the equitable amounts of *M. aegyptia* and *C. procera* biomass and goat manure incorporated into the soil in cropping cycles C1 and C2.

In a complementary manner, Aziz et al. (2025), when investigating the use of goat manure as organic fertilizer in Vietnamese coriander (*Persicaria odorata*), reported significant improvements in biomass, leaf morphology, and physiological quality of the plants, reinforcing the agronomic benefits of using organic fertilizers. Similar results were also

reported by Özyazici (2021), when evaluating the combination of organic and mineral fertilizers in coriander under semi-arid conditions, with a significant increase in biomass and plant height.

In Figure 3, it was possible to observe response patterns associated with the dynamics of nutrient release. This performance can be attributed to the gradual supply of nutrients to the soil, resulting from the mineralization of organic material and the synchrony established between nutrient release and crop demand. According to Ayamba et al. (2023) and Silva et al. (2023), the dynamics of mineralization depend on the nature of the input, the C:N ratio, and the degree of decomposition. Liu et al. (2024) reported in their research that organic fertilizers have a great influence on soil fertility, a factor that boosts plant productivity.

The responses showed a tendency to decline after the maximum doses, characterizing the physiological limit of the crop. According to the Law of the Maximum, plant growth is limited when the nutrient is in excess, restricting its development (ALMEIDA et al., 2015). According to Norgaard et al. (2022), in organic horticultural systems, there is a point of equilibrium between yield and nutrient use efficiency; beyond this point, efficiency is lost, potentially causing damage to the plants. Similar results were found by Desravines et al. (2022) and Freitas et al. (2024), when studying increasing amounts of green manure with *M. aegyptia* and *C. procera* in cowpea and carrot, respectively, reinforcing that amounts above the maximum point reduce nutrient use efficiency.

When comparing the responses from the two cropping cycles, C2 showed the highest values in number of stems, number of bunches, and green mass yield, indicating the influence of climatic conditions, which may have favored the decomposition of organic matter and the release of nutrients. Such variations can be justified by the more favorable temperature and humidity for microbial activity and nutrient absorption, as reported by Türkkan and Kibar (2022). In agreement, Sánchez-Navarro et al. (2023) found that the continuous application of organic compounds in semi-arid soils improves their chemical properties and increases the productivity of vegetables due to the progressive accumulation of organic matter in the soil.

Economic indicators for coriander

For the cultivation of 1 ha of coriander, the total production costs associated with the mixed organic fertilizers amounted to BRL 13,595.00, BRL 17,150.00, BRL 20,165.06, BRL 23,705.87, and BRL 27,306.68 for the equitable doses of 24, 42, 60, 78, and 96 t ha^{-1} of *M. aegyptia* biomass, *C. procera* biomass and goat manure, respectively. The control treatment (T_{wf}) generated a total cost of BRL 8,250.91, whereas the mineral fertilization treatment (T_{mf}) resulted in BRL 16,164.15 per cropping cycle. The expenses associated with organic fertilizers include operations such as biomass harvesting, transport, shredding, dehydration, bagging, field distribution, incorporation into the soil, and electricity used during processing. These costs scale according to the amount of biomass applied.

The analysis of variance for the economic indicators, namely gross income, net income, rate of return, and profit margin, is summarized in Table 3. Significant interactions were observed between the equitable quantities of *M. aegyptia* biomass, *C. procera* biomass, and goat manure and the cropping cycles, indicating differentiated economic performance under varying fertilization levels (Table 3).

Table 3. Mean values obtained for the control treatment (T_{wf}), the maximum economic efficiency treatment (MEE), the mixed organic fertilizer treatments (T_{mof}), and the mineral fertilizer treatment (T_{mf}) across cycles C1 and C2.

Comparison of treatments	Gross income (BRL ha^{-1})			Net income (BRL ha^{-1})		
	C1	C2	C1 - C2 (mean)	C1	C2	C1 - C2 (mean)
Control (without fertilization, T_{wf})	5250.00bA	6351.00bA	5800.00	-3001.00bB	-1900.00bA	-2451.00
MEE Treatment	43742.76aA	45995.05aA	44251.74^{+}	20627.10aB	21919.71aA	21482.33^{+}
Mixed organic fertilizer treatments (T_{mof})	35937.32aA	37690.36aA	36813.84^{+}	15552.80aB	17305.84aA	16429.32^{+}
Mineral treatment (T_{mf})	5851.00bA	12753.00bA	9302.00	-10313.00cB	-3411.00bA	-6862.00^{+}
CV (%)	6.45	9.32	8.17	19.11	23.93	22.34
	Rate of return			Profit margin (%)		
Control (without fertilization, T_{wf})	0.64bB	0.77bA	0.70	-65.39bB	-34.68bA	-50.04
MEE Treatment	1.97aB	2.00aA	1.98^{+}	49.76aB	50.15aA	50.08^{+}
Mixed organic fertilizer treatments (T_{mof})	1.77aB	1.87aA	1.82^{+}	42.88aB	45.92aA	44.40^{+}
Mineral treatment (T_{mf})	0.36bB	0.79bA	0.58	-183.09cB	-29.05bA	-1060.07^{+}
CV (%)	7.49	9.79	8.85	-486.56	57.21	204.87

*Means followed by the same lowercase letter within columns and uppercase within rows do not differ statistically from each other by F-test at a 5% probability level. $^{+}$Means of the treatments with mixed organic fertilizer, the MEE treatment, or the mineral fertilizer treatment are significantly different from the mean of the control treatment, according to the F-test at a 5% probability level.

The treatments achieving MEE, whether organic or mineral, differed markedly from the control for all economic variables. The MEE values were 7.6, 8.8, 2.8, and 1.0 times greater than those of the control for gross income, net income, rate of return, and profit margin. Across cropping cycles, significant differences were found for net income, rate of return, and profit margin within T_{mof}, T_{mf}, and T_{wf}, with C2 exhibiting superior economic outcomes.

When examining the equitable doses of mixed organic fertilizer within each cropping cycles, an increasing polynomial trend was detected in C1 and C2. The maximum responses recorded were BRL 43,742.76 (C1) and BRL 45,995.05 ha^{-1} (C2) for gross income, and BRL 20,627.10 (C1) and BRL 21,919.71 ha^{-1} (C2) for net income. The corresponding peak rate of return reached 1.97 (C1) and 2.00 (C2) Brazilian reais per real invested, with profit margins of 49.76% (C1) and 50.15% (C2). These maximum values for gross income, net income, rate of return, and profitability index were achieved with the total mixture of *M. aegyptia*, *C. procera*, and goat manure of 80.08 (C1) and 82.55 (C2), 67.76 (C1) and 73.57 (C2), 57.69 (C1) and 59.55 (C2), and 57.44 (C1) and 58.78 (C2) t ha^{-1}, respectively (Figures 4A, 4B, 4C and 4D).

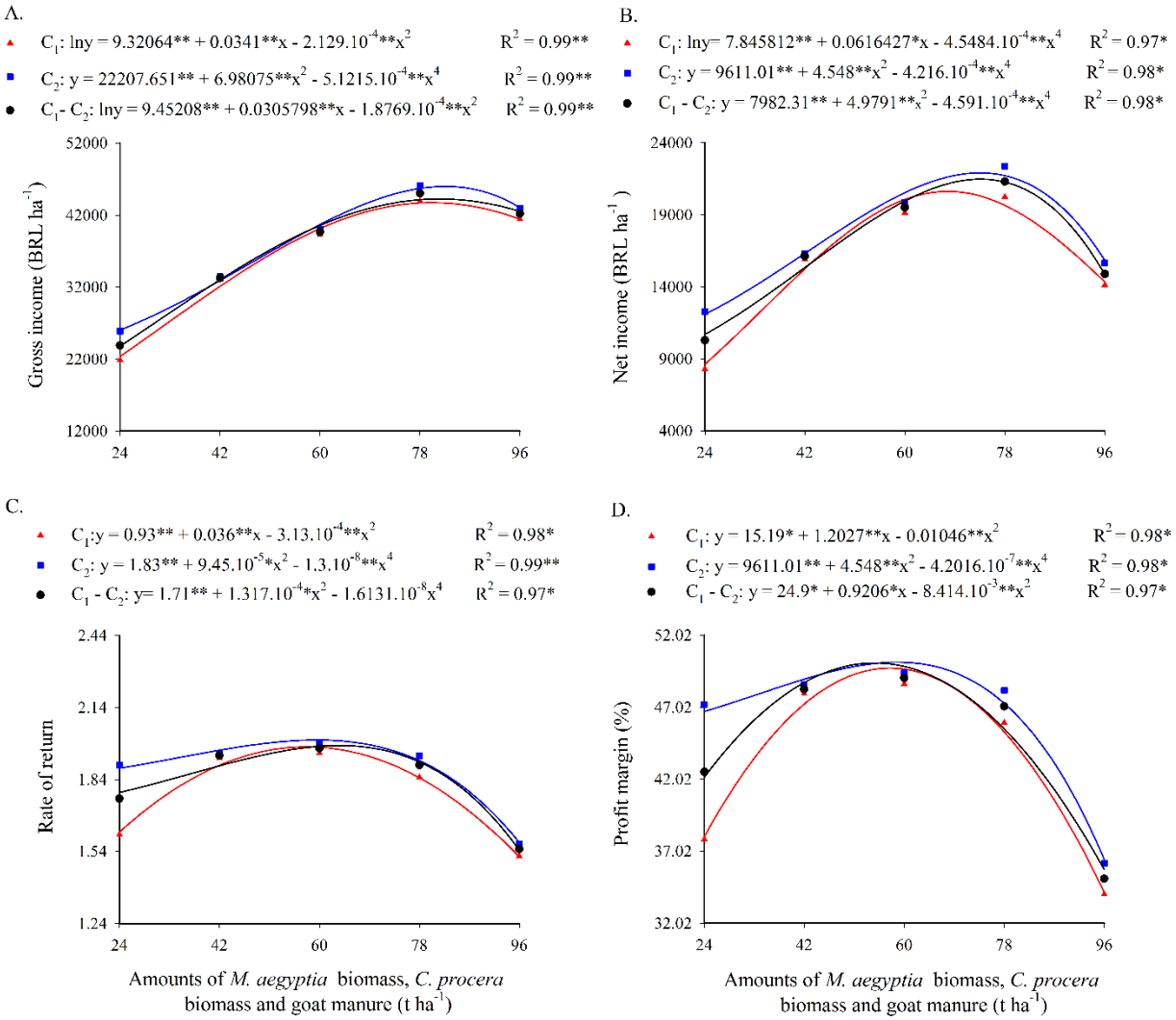


Figure 4. Gross income (A), net income (B), rate of return (C) and profit margin (D) of coriander, as a function of the equitable amounts of *M. aegyptia* and *C. procera* biomass and goat manure incorporated into the soil in cropping cycles C1 and C2.

The overall MEE estimates for the two cropping cycles also followed a polynomial response, increasing with fertilizer biomass until reaching maximum values of BRL 44,251.74 ha^{-1} for gross income, BRL 41,482.33 ha^{-1} for net income, 1.98 for the rate of return, and 50.08% for profit margin. These values correspond to biomass incorporations of 81.46, 73.63, 63.54, and 54.70 t ha^{-1} of *M. aegyptia*, *C. procera*, and goat manure, respectively. Beyond these optimal doses, economic performance declined, confirming the polynomial fit and indicating that excessive biomass inputs offer no additional economic advantage and may reduce profitability (Figures 4A, 4B, 4C and 4D).

The results of the analysis of economic indicators showed polynomial behavior, corroborating the pattern described by Ferreira et al. (2022) when applying *M. aegyptia* and *C. procera* biomass to coriander cultivation. This occurs because initial fertilizer doses significantly increase yields and profit. However, beyond a certain point, the high cost of

acquiring and applying larger amounts of organic matter exceeds the financial gain from the extra yield, reducing overall profitability.

Based on the MEE (maximum economic efficiency) treatment, economic indicators showed a decreasing trend after the maximum point, demonstrating that the use of mixed organic fertilizer optimizes not only the physical yield of crops but also the profitability of the production system. This behavior can be explained by the gradual and synchronized release of nutrients, which meets the physiological requirements of the crop while improving the chemical, physical, and biological properties of the soil, favoring moisture retention and stimulating microbial activity (SHEORAN et al., 2025).

These responses allow the producer to have greater flexibility in defining the quantities of organic fertilizer to be applied, according to the most advantageous economic indicator. Ferreira et al. (2022) and Souza et al. (2017) reinforce in their studies that the combination of organic fertilizers constitutes a relevant and economically viable strategy, integrating increased productivity, reduced costs, and the valorization of local resources. Similar results were observed by Migliorini and Wezel (2017), who highlight the contribution of organic and integrated systems to economic stability and productive resilience, especially in semi-arid regions with low availability of external inputs.

Beyond financial return, the use of local organic sources contributes to strengthening the rural economy and the autonomy of farmers, reducing dependence on external inputs and minimizing the environmental impacts associated with the use of mineral fertilizers (SILVA et al., 2023). Thus, the adoption of mixed organic fertilizers in coriander cultivation demonstrates potential to reconcile environmental sustainability, economic efficiency, and food security, strengthening the conservation of natural resources and indicating the viability of this management for the semi-arid region and for other vegetables.

CONCLUSION

Incorporating an equal-parts mixture of *M. aegyptia* biomass, *C. procera* biomass, and goat manure significantly improved the agronomic and economic performance of coriander under semi-arid conditions, highlighting the potential of this combination as an alternative for soil fertility management and sustainable crop production.

In the interaction between cropping cycles, the highest green mass yield and the greatest number of bunches were obtained with total application rates of the organic fertilizer mixture of 81.74 and 82.29 t ha^{-1}, respectively. Maximum economic efficiency regarding net income, rate of return, and profit margin was achieved with total mixture rates of 73.63, 63.54, and 54.70 t ha^{-1}, respectively. These results demonstrate that fertilization rates should be adjusted according to the production objective, with lower rates proving more economically efficient without compromising the coriander's yield potential.

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