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Original Article

Use of neem vegetable cake (*Azadirachta indica A. Juss*) increases corn productivity

Uso de torta vegetal de neem aumenta produtividade do milho

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Abstract

The need to transition to more sustainable agriculture that is adaptable to environmental challenges, reducing dependence on chemical fertilizers and minimizing environmental impact, represents the new paradigm of the moment. In this scenario, studies with the adoption of bioinputs in corn cultivation emerge as a viable option for the sustainability of agricultural activity. Therefore, the objective was to evaluate the effect of doses of neem vegetable cake on the yield components of corn crops. An experimental design was used of randomized blocks was used, consisting of four doses of neem vegetable rendering (3 kg ha^{-1}, 6 kg ha^{-1}, 9 kg ha^{-1} and 12 kg ha^{-1}) and a treatment control without the presence of organic fertilizer. The result indicates the presence of a significant effect of treatments with the application of neem cake on the main components of corn yield, including grain productivity, suggesting that the high carbon content present in the organic product can induce phytochemical effects and biological changes. in the soil, making it more productive. It was found that, when administering the maximum experimental dose, compared to the control group, there was a significant effect ($p \leq 0.01$) of 21.3% on grain productivity, jumping from 2,140 kg ha -^{1}, when did not apply organic fertilizer, to 2,596 kg ha-^{1} with the application of 12 kg of neem cake per hectare. It is noted that the increase in grain productivity was in the proportion of 38 kg ha-^{1} of corn for each kilo of neem cake applied. To facilitate interpretation and decision-making, an analysis of the economic viability of neem cake for rainfed corn was also determined, also identifying the maximum experimental dose of 12 kg ha-^{1}, as the most economically viable, providing an increase in profit of around R$ 119.92 per hectare, in relation to the control.

Keywords: organic fertilizer, commodity, *Zea mays* L.

Resumo

A necessidade de transitar para uma agricultura mais sustentável e adaptável aos desafios ambientais, com redução da dependência de fertilizantes químicos e minimização do impacto ambiental, representa o novo paradigma do momento. Nesse cenário, estudos com a adoção de bioinsumos na cultura do milho emergem como uma opção viável para a sustentabilidade da atividade agrícola. Portanto, objetivou-se avaliar o efeito de doses de torta vegetal de neem nos componentes de rendimento da cultura do milho. Utilizou-se um delineamento experimental de blocos casualizados constituídos pelas quatro doses da torta vegetal de neem (3 kg ha^{-1}, 6 kg ha^{-1}, 9 kg ha^{-1} e 12 kg ha^{-1}) e um tratamento testemunha sem a presença do adubo orgânico. O resultado indica a presença de um efeito significativo dos tratamentos com aplicação da torta de neem sobre os principais componentes de rendimento do milho, incluindo a produtividade dos grãos, sugerindo que o alto teor de carbono presente no produto orgânico pode induzir efeitos fitoquímicos e mudanças biológicas no solo, tornando-o mais produtivo. Verificou-se que, ao administrar a dose máxima experimental, em comparação com o grupo de controle, houve um efeito significativo ($p \leq 0,01$) de 21,3% na produtividade dos grãos, saltando de 2.140 kg ha -^{1}, quando não aplicou o adubo orgânico, para 2.596 kg ha-^{1} com a aplicação de 12 kg da torta de neem por hectare. Nota-se que o incremento na produtividade dos grãos foi na proporção de 38 kg ha-^{1} de milho para cada quilo de torta de neem aplicado. Para facilitar a interpretação e tomada de decisão, determinou-se também a análise de viabilidade econômica da torta de neem para a cultura do milho cultivado em sequeiro, identificando também a dose máxima experimental de 12 kg ha-^{1}, como a mais viável economicamente, proporcionando um incremento no lucro na ordem de R$ 119,92 por hectare, em relação a testemunha.

Palavras-chave: fertilizante orgânico, commodity, *Zea mays* L.

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1. Introduction

In Brazil, due to its high adaptability, corn (*Zea mays* L.) is widely cultivated and has become one of the main cereals produced in the country (CONAB, 2023a), reaching, with its three annual crops, the position of the third-largest producer and the largest exporter of corn globally, one of the three most cultivated cereals in the world (Coelho, 2023). To give an idea of this magnitude, the 2022/2023 crop of this commodity was estimated at 131.9 million tons of grains, with an average yield of around 5.92 t ha^{-1} and a planted area of 22.2 million hectares (CONAB, 2023b), thus confirming the understanding of Radünz et al. (2022) who believe in the great importance of corn production for Brazil.

Unlike the main corn-producing regions in Brazil, the Northeast region, like other cereal-producing regions worldwide, has significantly lower grain yields compared to this national average, and the explanation can be attributed to a series of edaphoclimatic, economic, and technological factors. According to Janini et al. (2022), to achieve high yields, other factors need to be adjusted for crop optimization, especially the agricultural management used throughout the plant's cycle.

Fertilization, one of the essential practices when well conducted, has the potential to positively influence the productivity of any crop. In corn, especially when high technology is applied, there is a strong dependence on chemical fertilization, particularly nitrogen, to achieve maximum crop yield. Despite this, and despite the fact that the availability of synthetic fertilizers motivates the increase in planted area and global grain production, the supply of this input must be carried out responsibly; otherwise, it will cause environmental damage, nutritional imbalances due to antagonism, and soil degradation. Another factor to be considered with the use of chemicals is the high cost and dependence on international markets. To give an idea, Brazil is the fourth-largest consumer of chemical fertilizers and consumes about 83% of its imported fertilizers, which burdens agricultural production (Zonta et al., 2021).

The pursuit of a more sustainable and resilient agriculture to environmental challenges, with less dependence on chemical fertilizers and generating less impact on the environment, has become the new challenge of the moment. In this sense, for Marchese and Filippone (2018), bioinputs are an increasingly present alternative in crop management, as they can complement conventional management by representing economically attractive and ecologically acceptable options.

A biological product whose purpose is to act on the fertility and nutrition of the plant, which promises to improve the physical and chemical characteristics of the soil is neem vegetable cake. A simple "A" class organic fertilizer (Brasil, 2020), which aims to increase crop productivity through a natural source of nutrients. Therefore, we believe that the use of bioinputs, such as neem cake, in corn cultivation represents not only a promising strategy, but also a viable solution to face environmental challenges and promote more sustainable agriculture, providing tangible improvements that contribute to the transition to a more sustainable agricultural system that is adaptable to environmental challenges.

That said, the present research aimed to evaluate the effect of doses of neem vegetable cake on productivity and other yield components of the corn crop.

2. Materials and Methods

2.1. Characterization of the experimental area

The work was conducted during the agricultural year 2023, from April to August, at the Chã-de-Jardim Experimental Farm (06º 58' 08'' S and 35º 44' 00'' W, altitude 619 m), belonging to the Center for Agricultural Sciences at the Federal University of Paraíba, Campus II, located in the municipality of Areia, in the microregion of Brejo Paraibano. The soils in the study region are classified as Dystrophic Typic Yellow Latosol, with a sandy clay loam texture (Santos, 2018), with 320 g kg^{-1} of clay, 93 g kg^{-1} of silt, and 587 g kg^{-1} of sand. According to Köppen's classification, the climate in the region is As', hot and humid with autumn-winter rains and average annual precipitation ranging from 1.200 to 1.400 mm, concentrated mostly from April to July, with an average annual temperature ranging between 22 to 26 ºC and relative humidity between 75 to 87% (Ribeiro et al., 2018). During the experiment, the accumulated rainfall was 792.2 mm, well-distributed (Figure 1) with higher incidences in June (INMET, 2023).

To perform the chemical and physical characterization of the experimental area and subsequently determine fertilization and liming recommendations, four individual soil samples were collected from the 0-20 centimeter layer. These samples were later combined into a single composite sample, which was sent to the Soil Laboratory of the Federal University of Paraíba for analysis (Table 1).

2.2. Experimental design and treatments

The experimental design adopted was randomized blocks, with five treatments and four replications. The treatments consisted of four doses of neem cake (3 kg ha^{-1}, 6 kg ha^{-1}, 9 kg ha^{-1}, and 12 kg ha^{-1}) and a control treatment without the presence of organic fertilizer. To compose the treatments, the doses of neem cake,

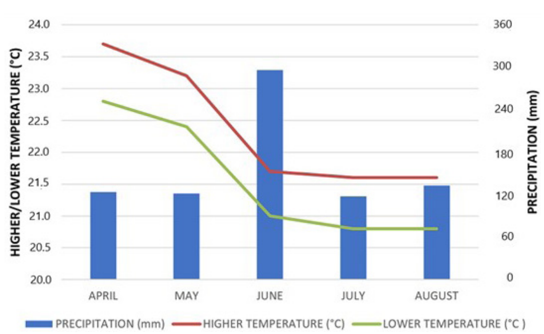

Figure 1. Climatic characterization in the city of Areia-PB during the experimental period.
Source: INMET (2023).

Table 1. Chemical attributes of the soil at Chã-de-Jardim Experimental Farm, Areia, Paraíba, Brazil, 2023.

pH	N	P	K^+	Na^+	H+Al	Al^{3+}	Ca^{2+}	Mg^{2+}	SB	CTC	OM
(water)	g/kg^{-1}	mg dm^{-3}		cmolc dm^{-3}							$g\ kg^{-1}$
6.30	-	2.46	56.80	0.04	4.95	0.05	3.97	2.04	6.19	11.14	29.79

Source: Authors (2023)

whose composition is in Table 2, were weighed in the recommended quantities for the experimental area, diluted in water, and placed in 2-liter PET bottles. The mixture rested in a low-light location for a period of 24 hours before application. The applications of the filtered product (solution extraction) were carried out in liquid form via soil, manually using a 20-liter backpack sprayer, in the V3, V5, and V8 stages of crop development.

The experimental plots were composed of four single rows, delimited with dimensions of 3.3 m x 5.0 m (16.5 m^2), and a spacing of 0.80 m between rows, considering only the two central rows (3.75 m^2) as the useful area, disregarding the borders.

Table 2. Guaranteed Levels of Neem Vegetable Cake

Organic Fertilizer Simple Class A	
Azadiractina	Above 1000 PPM
Total Nitrogen	4%
Total Organic Carbon	40%
CEC	200 mmolc/kg
CEC/C ratio	5
Maximum moisture	12%
pH	5.0

Source: Composition of the neem cake used in the experiment.

2.3. Implementation and experimental conduct

For the initial soil preparation, plowing and two harrowings were performed, followed by furrowing the area. At planting time, the experimental area received base fertilization with 200 kg ha^{-1} via granulated fertilizer (40% P, 9% N, 5% S, 4% Ca, 0.1% Zn, 0.05% Mn, and 0.03% B). Additionally, for topdressing, 40 kg KCl ha^{-1} was used via potassium chloride (48% KCl) at the V4 phenological stage, and 100 kg N ha^{-1} via urea (45% N), divided into 60% at the V5 phenological stage and 40% at the V8 phenological stage.

The corn used in the experiment was Hybrid B2620PWU, an early-cycle hybrid with good plant stature, pronounced stay green, good tolerance to the complex of smuts, good performance under water stress, and high productive potential (Brevant, 2023).

As needed, using a backpack sprayer, applications of foliar fertilizers, as well as phytosanitary products for pest and disease control in corn, were carried out (Table 3).

At the end of the cycle, after corn harvest and evaluation of yield components, a new soil analysis was performed (Table 4) using samples collected from the 0-0.20 m layers of each plot, which were later combined to form representative composite samples for each treatment.

2.4. Evaluated variables

Corn harvest was performed manually right after the grains reached physiological maturity, specifically between 8 and 10 days after the R6 reproductive development stage. All ears from the useful area of each plot were harvested, disregarding the border. To evaluate yield components, five ears from each plot were randomly chosen to measure the following yield components:

Ear Length (EL): obtained by measuring the average length of the five selected ears in the useful area of each plot, determining the average length between the first and last grain of the longest row of the spread ear. The measurement was taken with the help of a graduated tape, and the data were obtained in centimeters (Miranda et al., 2018).

Ear Diameter (ED): obtained by measuring the average diameter of the five selected ears in the useful area of each plot, determining the average diameter based on the sampling of the average position of the ear. The measurement was taken with the help of a caliper, and the data were obtained in millimeters (Miranda et al., 2018).

Average Ear Weight (EW): obtained by evaluating the average weight of the five selected ears in the useful area of each plot, determining the average weight with the help of an analytical balance.

Thousand-Grain Weight (TGW): estimated using the formula (TGW = Sample Weight x 1000 / Total Number of Seeds), where eight random samples of 100 grains, taken from the five selected ears in the useful area of each plot, were weighed separately, and then the variance, standard deviation, and coefficient of variation of the obtained values were calculated, not identifying variation above the 4% limit (Brasil, 2009). For this selection, all ears from each plot were mechanically threshed, discarding damaged and defective grains from weighing, leaving only whole grains. For weighing, a precision scale was used in conjunction with a plastic container.

Grain Yield (GY): obtained by evaluating the yield of all ears in the useful area of each plot. Ears were mechanically threshed and then weighed, converting g m^{-2} to kg ha^{-1}.

2.5. Economic viability analysis

Considering that the costs of implementing and conducting the experiment were proportionally divided for the entire experimental area, the only values that really differentiated between treatments were the quantity of neem cake used and the labor involved in this application. Thus, to estimate the economic viability of implementing 1 hectare of corn, all variable costs involved in complementary fertilization with neem cake and the financial return from the treatments compared to the control were considered.

Table 3. Foliar fertilizers and phytosanitary products sprayings in corn cultivation in the experimental area. Areia, state of Paraíba, Brazil.

Application	Purpose	Period	Commercial Product and Dosage
1°	Insecticide/Fungicide	V8	Lannate – 0.5L ha $^{-1}$ + Aproach - 1L p.c ha $^{-1}$
2°	Foliar Fertilizer	V9	Zintrac – 0.5L p.c ha $^{-1}$ + Thiotrac – 1.5L p.c ha^{-1} + Phosamco Bio – 0.5L p.c ha^{-1}
3°	Fungicide	R5	FitoNeem – 1.5L ha $^{-1}$ and Azimut – 0.5L p.c. ha^{-1}

Source: Authors of the work (2023).

To identify the neem cake dosage that presented the best economic viability, it was necessary to find the difference in productivity (DP), obtained by subtracting the productivity values found at different doses of neem cake from the productivity found in the control. It was estimated by Equation 1:

$$DP = PRODdose - PRODcontrol \qquad (1)$$

Next, it was necessary to determine the extra gain (EG) for each dose, initially transforming the productivity difference into 60 kg sacks (the way corn is marketed), and then multiplying by the corn sack value. Due to the constant market fluctuations, this work adopted the average value of corn marketed in 2023, which was R$ 65.91 per 60 kg sack (Cepea, 2023). The extra gain (EG) was estimated by Equation 2:

$$EG = ExtraSackNumber \text{ x } SackValue\ 60Kg\left(R\$\right) \qquad (2)$$

Economic viability (EV) was determined through the contribution margin of each treatment, comparing the extra gain (EG) obtained with the commercialization of each production and the extra costs (EC) with the application of neem cake obtained by each treatment. It was estimated by Equation 3:

$$EV = EG - EC\ neemcake + laborcosts\ \left(R\$\right) \qquad (3)$$

2.6. Statistical analysis

The data were subjected to analysis of variance (ANOVA) by the F-test ($p<0.05$). For the doses, polynomial regression analysis was employed, and, with the F-test of regression variance significant at 5%, models were selected, adopting as criteria the highest R^2 and the significance of 5% of the equation coefficients. All analyses were performed using the statistical software R, version 4.3 (R Core Team, 2020).

3. Results

The analysis of variance for the data indicates a significant effect of treatments with neem cake application on the main variables analyzed, including grain productivity ($p\leq0.01$). Among the investigated yield components, only the thousand-grain weight was not affected by the treatments. Furthermore, like the other variables, it also showed a low coefficient of variation, suggesting that the tested inferences are accurate, and the experiment was conducted in a targeted manner (Table 5).

Regarding the individual impact of treatments, the increase in neem cake doses had a quadratic effect on ear length (EL), with the regression equation revealing that 10.24 kg ha^{-1} is the optimal dose of the product capable of promoting the best result for this characteristic (Figure 2A). This optimal dose, when compared to the control, had a significant effect ($p\leq0.01$), increasing ear length by 19.38%.

For ear diameter (ED), a progressive increase was observed as neem cake doses increased, with the data being linearly adjusted through the regression equation and the coefficient of determination R^2 (Figure 2B). The results showed that the application of high doses of the product significantly increased ($p\leq0.05$) ear diameter by up to 6.3% compared to the control, indicating an increase of up to 3 mm in the average variable value based on the applied product quantity.

Concerning the number of rows per ear (NRE), a quadratic regression model was used to fit the data, with the regression equation revealing that the maximum assimilation dose of the product, to achieve the best result, was 6.63 kg ha^{-1} (Figure 2C). At this dose, the number of rows per ear significantly increased ($p\leq0.05$) by 7.91% compared to the population that was not fertilized with neem cake.

As illustrated in Figure 2D, there was a progressive increase in the number of grains per row (NGF) as the neem cake dose applied increased, with the maximum response to the product being adjusted at 9.84 kg ha^{-1}. At this dose, when compared to the control group, there was a significant effect ($p\leq0.05$), increasing the number of grains per row by 19.83%.

For the number of grains per ear (NGE), a progressive increase was also observed as neem cake doses increased, but with the regression equation adjusting the optimal dose of the product at 8.25 kg ha^{-1} (Figure 2E). With a significant effect ($p\leq0.01$), the use of this dose, compared to the control, resulted in a 27.26% adjustment in the studied variable.

In the case of ear weight (EW), neem cake doses also had a quadratic effect, with the regression equation of the data revealing that 9.75 kg ha^{-1} is the limit dose that would determine the best result for this characteristic (Figure 2F). For this yield component, the significant effect ($p\leq0.05$) of this dose was even more pronounced, promoting a 30.45% increase when compared to the control.

A linear regression model was also developed to fit the variable yield (GY) data. According to the regression equation and coefficient of determination R^2, the highest productivity was achieved with the application of the highest experimental dose of the product. It was found

Table 4. Soil chemical properties for each treatment with neem cake doses in the Chã-de-Jardim Experimental Area. Areia, Paraíba, Brazil, 2023.

Doses ($kg\ ha^{-1}$)	pH	N	OM	P	K^+	Cu	Fe	Mn	Zn	Na^+	H+Al	Al^{3+}	Ca^{2+}	Mg^{2+}	SB	CEC	V
	(water)	g/kg^{-1}	g/kg^{-1}	$mg\ dm^{-3}$						$cmolc\ dm^{-3}$							%
0	6.20	1.75	32.8	10.4	47.8	0.00	21.1	1.69	1.00	11.4	3.47	0	5.00	2.20	7.37	10.84	68
3	6.00	1.51	30.2	7.9	57.3	0.02	25.7	1.80	1.04	31.5	4.13	0	5.20	0.90	6.38	10.51	61
6	6.30	1.83	30.0	19.4	55.4	0.00	18.5	1.92	1.33	13.4	3.14	0	5.80	1.60	7.60	10.73	71
9	6.20	1.67	30.8	19.4	72.6	0.00	23.3	1.46	1.05	12.4	4.29	0	5.00	2.20	7.44	11.73	63
12	6.20	1.72	31.2	23.8	53.5	0.00	20.9	1.41	1.10	10.5	4.13	0	5.00	1.50	6.68	10.81	62

OM – Organic Matter; P, K^+, and Na^+ extracted with $Mehlich^{-1}$. SB: sum of bases. CEC: cation exchange capacity. V: Base saturation.
Source: Authors (2023)

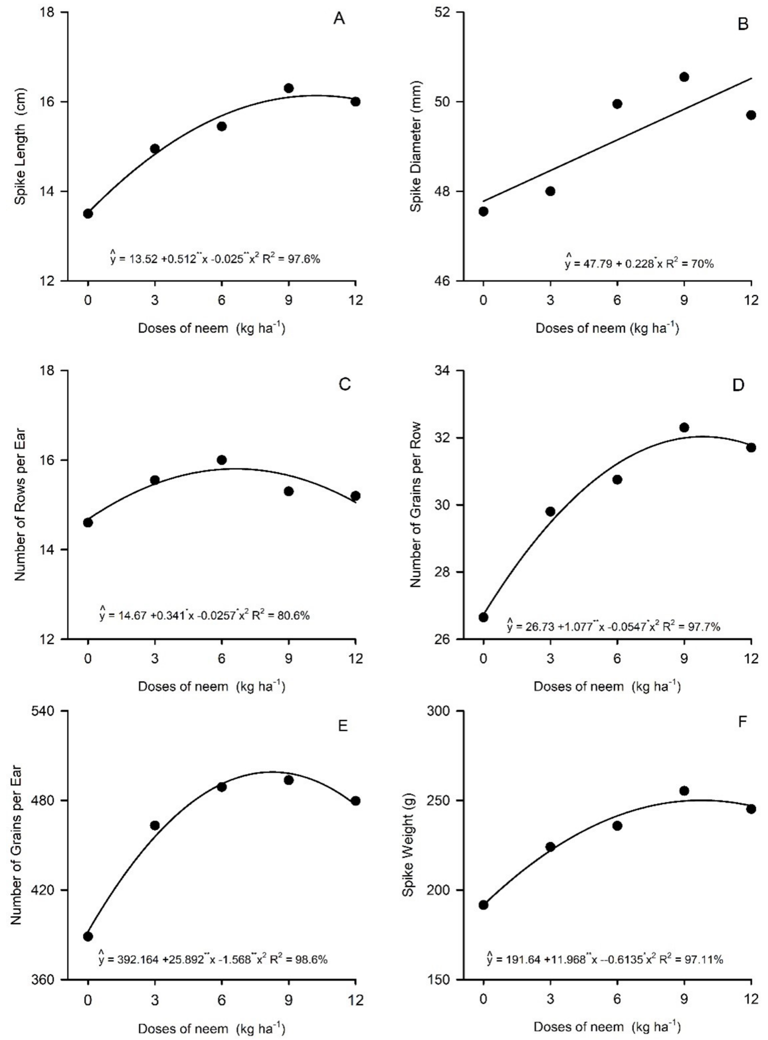

Figure 2. Effect of neem cake doses on corn crop regarding ear length (A), ear diameter (B), number of rows per ear (C), number of grains per row (D), number of grains per ear (E), and ear weight (F), in the municipality of Areia, state of Paraíba, Brazil.
Source: Developed by the authors (2023).

Table 5. Summary of the analysis of variance of an experiment with maize, subjected to neem cake doses. The analyzed variables were: ear length (EL), ear diameter (ED), number of rows per ear (NRE), number of grains per row (NGR), number of grains per ear (NGE), ear weight (EW), weight of a thousand grains (WTG), and productivity (PROD). Areia, Paraíba, 2023.

SV	DF	F calculated						WTG	PROD
		EL	ED	NRE	NGR	NGE	EW		
Blocks	3	2.64	12.41	0.96	1.80	3.91	3.25	0.67	15.30
Treatments	(4)	19.05	2.69	2.79	8.23	12.80	9.58	0.83	7.34
Linear	1	63.25**	7.43*	0.96	26.52**	31.16**	30.42**	2.02	24.58**
Quadratic	1	11.12**	1.76	8.03*	5.68*	19.33**	6.78*	0.30	0.002
Residue (MS)	12	0.26	2.53	0.38	2.40	577.30	251.68	126.73	0.06
Total	19								
CV (%)		2.6	2.5	3.1	4	4	5.3	2.1	4.7

SV – Source of Variation; DF – Degree of freedom; ** – significant at 1% (P<0.01) by F test; * – significant at 5% (P<0.05) by F test. MS – Mean Square; CV – Coefficient of variation.
Source: Authors of the work.

that by administering the maximum experimental dose, compared to the control group, there was a significant effect ($p \leq 0.01$) of 21.3% on grain productivity, jumping from 2.140 kg ha^{-1} when neem cake was not applied (control) to 2.596 kg ha^{-1} with the application of 12 kg of neem cake per hectare (Figure 3). It is noteworthy that the increase in grain productivity was in the proportion of 38 kg ha^{-1} of corn for each kilogram of neem cake applied.

After evaluating yield components, a new characterization of soil chemical properties was performed (Table 4), and the results showed that, compared to the control, supplying organic fertilizer did not result in significant accumulations in soil organic matter and nitrogen levels. That the carbon provided through liquid fertilization may have been rapidly converted into biomass, contributing to increased productivity without a corresponding accumulation in the soil.

Parallel to the productivity results, to aid in interpretation and decision-making, an economic viability analysis of neem cake for rainfed corn cultivation was determined. Considering the information presented in Table 6, the neem cake dosage that showed the best economic viability was the maximum experimental dose of 12 kg ha^{-1}, providing an increase in profit in the order of R$ 119.92 per hectare compared to the control. It was not possible, through the results, to determine the assimilation limit dose of the product.

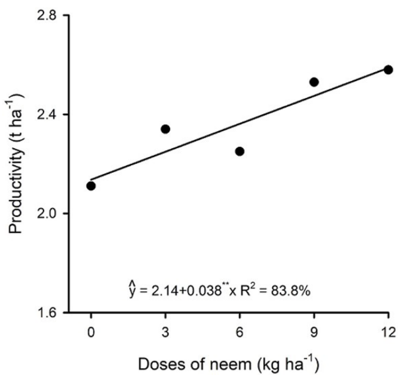

Figure 3. Effect of neem cake doses on corn crop yield in Areia, Paraíba, Brazil.
Source: Developed by the authors (2023).

4. Discussion

Deepening the study on the application of organic fertilizers is essential to foster sustainable agricultural methods that protect soil diversity and promote the production of healthier food. The use of neem cake in corn cultivation fills important gaps in the context of sustainable development in large-scale agriculture, offering significant insights into more balanced agricultural practices, promoting responsible use of natural resources, and contributing to agricultural systems that reconcile productivity with environmental preservation (Singh et al., 2020).

According to the evaluations and results obtained, it is evident that fertilization with neem cake positively influenced corn productivity and the main yield parameters. The positive effects observed on productivity (Figure 3) were consistent and progressively increased as neem cake doses increased.

The set of findings indicates that, under the defined study circumstances and limitations, the experiment on organic fertilization with neem cake was successful and has the potential to benefit producers, society, and the environment. The adoption of these practices may result in more abundant harvests, lower costs associated with input acquisition, and the use of natural nutrient sources. Furthermore, successful experiments like this one (Lima et al., 2020) can benefit their products by linking to higher levels of food security and health, lower social and environmental externalities, meeting consumer expectations.

This study notably corroborates with the recently reported findings by Wei et al. (2020) regarding the effectiveness of organic fertilizers in corn cultivation. The convergence of results between the research strengthens the evidence base for the use of organic fertilizers in this context. This agreement

Table 6. Economic Viability of neem cake for the cultivation of 1 hectare of maize in rainfed system, 2023.

Dose	Productivity	DP	Extra Bags	Bag 60kg	Extra Gain	Neem Cost	OM Cost	Extra Cost	EV
(kg/ha)	(kg/ha)	(kg/ha)	(60kg)	(R$)	(R$/ha)	(R$/ha)	(R$/ha)	(R$/ha)	(R$/ha)
0	2140.00	0.00	0.00	65.91	0.00	0.00	0.00	0.00	0.00
3	2254.00	114.00	1.90	65.91	125.23	84.00	45.00	129.00	-3.75
6	2368.00	228.00	3.80	65.91	250.46	168.00	45.00	213.00	37.46
9	2482.00	342.00	5.70	65.91	375.69	252.00	45.00	297.00	78.69
12	2596.00	456.00	7.60	65.91	500.92	336.00	45.00	381.00	119.92

DP – Difference in Productivity. Extra bags (60 kg) – Difference in productivity converted into 60 kg bags. Bag 60 kg (R$) – Average of the values traded for maize in Brazil in 2023, as reported by Cepea. Extra Gain (R$) – Value received from the commercialization of extra bags. Neem Cost (R$) – Cost with the neem cake dose. OM Cost (R$) – Cost with labor for the three applications of neem cake, at stages V3, V5, and V8. Extra Cost (R$) – Sum of Neem Cost (R$) and Labor Cost (R$). EV – Economic Viability in R$/ha, found by confronting the extra gain minus the extra costs.
Source: Authors of the work.

not only validates the robustness of the presented data but also extends the generalization of these results beyond the individual scope of a single study. This alignment among different scientific sources provides a solid foundation for practical recommendations in agricultural management, highlighting the importance of organic fertilizers as viable and sustainable alternatives in corn cultivation.

One possible explanation for this effectiveness lies in the fact that the organic fertilizer with neem cake contains 40% Total Organic Carbon in its composition (Table 2), and according to Vida et al. (2020), this high carbon content can induce phytochemical effects and biological changes in the soil, making it capable of restoring its properties and improving its quality. In the understanding of Bettiol et al. (2023), higher carbon storage in the soil ensures more available water for plants, improves nutrient supply, and, particularly, increases nitrogen availability in the soil-plant system, thus tending to be more productive.

The improvement in nutrient availability promoted by this complex interaction between the rhizosphere and carbon-rich soil, where processes like the release of root exudates in the presence of beneficial microorganisms and soil structure quality positively influence nutrient assimilation by plants. According to Gao et al. (2020), the increased absorption of these essential nutrients by plants contributes to the improvement of grain quality, translocating to the seed, thereby enhancing the content of amino acids, starch, carbohydrates, and proteins.

Revisiting the productivity data (Figure 3), but this time from the perspective of economic viability (Table 6) and profit optimization, the results obtained in the experiment were not able to determine the limit dose to achieve the highest productivity, highlighting the need for further research with higher product doses. Thus, believe that this study will enable other experiments with the use of Class A organic fertilizers, such as neem cake, to be developed and improved for other major crops, contributing to a more solid knowledge base involving sustainable agriculture.

5. Conclusions

The study compellingly highlights that Class A organic fertilizer, commercially known as neem cake, increased rainfed corn productivity and positively influenced the main yield components of corn. The use of the product assists in the sustainable absorption of essential nutrients by enhancing soil properties and stimulating beneficial microbial activity.

Based on the results evidenced in this work, we believe that the implementation of sustainable practices, such as the use of organic fertilizers, not only optimizes agricultural productivity but also plays a fundamental role in transitioning to more balanced agricultural systems, promoting ecosystem resilience, biodiversity conservation, and reducing environmental impacts.

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