

Agronomic evaluation and economic efficiency of vegetable soybean and organic fertilization

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ABSTRACT

Despite its growing popularity in Western diets, vegetable soybean remains relatively underexplored in terms of cultivar performance and management practices. This study aimed to evaluate the agronomic performance and economic efficiency of vegetable soybean cultivars in response to varying doses of poultry litter. The experiment was conducted in Aquidauana, MS, Brazil, utilizing a 2 x 4 factorial design that included two vegetable soybean cultivars (BRS 232 and BRS 267) and four poultry litter doses (6, 12, 18, and 24 t ha⁻¹). The experimental setup followed a randomized block design with four replications. The following agronomic parameters were evaluated: plant height, first pod insertion height, 100-immature grain weight, green pod yield, total yield of immature grains, and number of pods per plant, as well as the following economic indices: gross income, net income, return rate, and profitability index. The cultivar BRS 232 demonstrated superior agronomic and economic performance, with agronomic optimum at 16.36 t ha⁻¹ and economic optimum at 6 t ha⁻¹. However, for the BRS 267 cultivar, it was not possible to establish predictive equations for most economic and agronomic indices, except for the first pod insertion height and the 100-grain weight. Consequently, poultry litter is a cost-effective and profitable option for producers and adequately meets the nutritional requirements of vegetable soybeans.

Keywords: *Glycine max* L. Merrill, Green soybean, Poultry litter, Economic analysis.

Avaliação agrônômica e eficiência econômica de cultivares de soja-hortaliça e adubação orgânica

RESUMO

A soja-hortaliça, mesmo com recente notoriedade na alimentação ocidental, é pouco explorada quanto ao desempenho de cultivares e forma de manejo. Este trabalho teve como objetivo avaliar o desempenho agrônômico e eficiência econômica de cultivares de soja-hortaliça em função de doses de cama aviária. O experimento foi conduzido em Aquidauana, MS, Brasil. Foram estudados seis tratamentos em esquema fatorial 2 x 4, sendo duas cultivares de soja-hortaliça (BRS 232 e a BRS 267) e quatro doses de cama aviária (6, 12, 18, 24 t ha⁻¹). O delineamento experimental adotado foi de blocos casualizados com quatro repetições. Foram avaliados os seguintes parâmetros agrônômicos: altura da planta, altura de inserção da primeira vagem, peso de 100 grãos imaturos, produtividade de vagens verdes, produtividade total de grãos imaturos e número de vagens por planta, bem como os seguintes índices econômicos: renda bruta, renda líquida, taxa de retorno e índice de lucratividade. O melhor desempenho agrônômico e eficiência econômica foram obtidas com 16,36 t ha⁻¹ e 6 t ha⁻¹, respectivamente, com destaque para cultivar BRS 232. Entretanto, para cultivar BRS 267 não foi possível o ajuste de equações para os índices econômicos e agrônômicos estudados, exceto para altura de inserção da primeira vagem e peso de 100 grãos. A cama aviária é, portanto, uma opção de baixo custo e rentável ao produtor ao mesmo tempo que supre as demandas nutricionais da soja-hortaliça.

Palavras-chave: *Glycine max* L. Merrill, Soja verde, Cama aviária, Análises econômicas.

1. Introduction

Vegetable soybean (*Glycine max* (L.) Merrill), primarily cultivated in China and Japan (Dong et al., 2014), has large seeds and a sweet flavor (Nair et al., 2023). The pods are harvested at the R6 growth stage, when seed moisture content is high. These fresh pods are typically sold refrigerated or pre-cooked, enabling diverse culinary uses, including incorporation into salads (Fogelberg and Mårtensson, 2021; Jiang et al., 2018b).

The popularity of vegetable soybeans is increasing in Western markets, driven by their palatability and superior nutritional profile (Ribera et al., 2022). They are rich in macronutrients, vitamins (Djanta et al., 2020), essential amino acids, isoflavones, phenolic compounds, and other antioxidants (Zhang et al., 2017), often exhibiting a nutritional composition that exceeds that of traditional grain soybeans (Djanta et al., 2020). Brazil, a dominant global producer of grain soybeans, has significant potential to expand vegetable soybean production due to its favorable soil and climatic conditions (Ribera et al., 2022). However, to scale production, it is imperative to develop and deploy cultivars that are specifically adapted to Brazil's diverse agroecological zones, given the crop's sensitivity to environmental and management variations (Jankauskienė et al., 2021).

Optimizing the performance of well-adapted vegetable soybean cultivars through appropriate management practices can substantially increase yield and profitability (Guo et al., 2020). The development and implementation of conservation-oriented agricultural practices that reduce input costs, minimize soil degradation, and enhance crop yield are critical. Fertilization strategies play a central role in this context, as they directly influence crop growth and yield.

Organic fertilizers can meet crop nutritional requirements by releasing nutrients in alignment with plant uptake (Cardoso et al., 2020). Effective management of organic fertilizers, through the application of optimal doses, not only reduces nutrient losses but also ensures efficient nutrient assimilation by the crop (Oliveira et al., 2024). Poultry litter is a particularly effective organic fertilizer, known for its slow nutrient release characteristics, contributions to soil organic carbon and phosphorus levels, and enhancement of soil organic matter and biological activity. It is regarded as a sustainable practice that, when properly managed, mitigates the environmental impacts typically associated with the use of synthetic fertilizers (Blair et al., 2014; Nordi et al., 2022).

The incorporation of poultry litter into soil management practices is well-documented for its ability

to enhance crop yields and stabilize soil structure (Blair et al., 2014). However, comprehensive analyses of the agronomic performance and economic returns associated with the use of poultry litter in vegetable soybean cultivation remain underexplored. Therefore, this study aimed to assess the agronomic performance and economic efficiency of vegetable soybean cultivars under rates of poultry litter fertilization.

2. Material and Methods

The study was conducted from October 2017 to March 2018 at the State University of Mato Grosso do Sul, located in Aquidauana, within the Cerrado-Pantanal ecotone. The climate, classified as Aw according to the Köppen classification, is characterized by a tropical regime with dry winter and rainy summer. The region has an average annual precipitation of 1200 mm, with mean maximum and minimum temperatures of 33 °C and 19 °C, respectively. Meteorological data recorded by the weather station of the State University of Mato Grosso do Sul showed that during the experimental period, total precipitation was 971 mm, while the average maximum and minimum temperatures were 37 °C and 18 °C, respectively, and relative humidity ranged from 39% to 95%. The soil was classified as Argissolo Vermelho, with sandy loam textural class (Schiavo et al., 2010).

A 2 x 4 factorial design was employed, comprising two vegetable soybean cultivars (BRS 232 and BRS 267) and four poultry litter doses (6, 12, 18, 24 t ha⁻¹). The experimental design was a randomized block design with four replications. Each experimental unit covered an area of 2.88 m², with a useful area of 1.60 m², and plants were spaced 0.40 m between rows and 0.10 m within plants, resulting in 10 plants per meter. A total of 40 plants per plot were assessed.

Prior to the experiment installation, soil samples were collected from a depth of 0 to 20 cm and analyzed using the methodologies described by Silva and Silva (2009). The soil attributes obtained were: pH = 5.5 in CaCl₂; P = 68 mg dm⁻³; K = 2 mmol_c dm⁻³; Ca = 74 mmol_c dm⁻³; Mg = 26 mmol_c dm⁻³; Al = 0 mmol_c dm⁻³; H+Al = 22 mmol_c dm⁻³; Cu = 1.1 mg dm⁻³; Fe = 104.6 mg dm⁻³; Mn = 43.8 mg dm⁻³; Zn = 9.5 mg dm⁻³; B = 0.23 mg dm⁻³; S = 5 mg dm⁻³, and OM = 34 g dm⁻³.

Beds were prepared, and seven days before sowing, manure was incorporated into the 0–0.20 m soil layer at the recommended rates, allowing sufficient time for nutrient release from the organic material. Following seed inoculation, sowing was performed in October 2017 at a spacing of 2.40 m × 1.20 m, according to the factorial scheme. Irrigation was implemented using a

sprinkler system, with a flow rate of $2.87 \text{ m}^3 \text{ h}^{-1}$ and a service pressure of $30 \text{ mH}_2\text{O}$, on a daily irrigation schedule. Manual weeding was performed as needed. Harvesting was performed manually at three intervals (January, February, and March 2017), beginning at the R6 growth stage, when the pods contained immature seeds.

The following attributes were assessed for ten plants from the useful area: a) plant height (cm): measured from the base of the plant to the apex; b) first pod insertion height (cm): measured from the base of the plant to the insertion of the first pod; c) 100-green grain weight (g): obtained by weighing 100 immature grains; d) green pod yield (kg ha^{-1}): calculated using the following expression $((\text{weight of green grains}/1000) \times 10000/0.5) \times 0.7$, where 0.7 refers to a 70% yield factor; e) total yield of immature grains (t ha^{-1}): calculated from plant density, number of pods per plant, average number of seeds per pod, and the 100-immature grain weight; and f) number of pods per plant: number of pods counted from plants in the usable area.

The economic performance of vegetable soybean was evaluated using the following metrics, as proposed by Guiducci et al. (2012): a) gross income ($\text{R\$ ha}^{-1}$): calculated by multiplying the crop yield by the prevailing market price during the harvest period; b) net income ($\text{R\$ ha}^{-1}$): calculated by subtracting the production costs, labor, machinery, and input expenses, from the gross income; c) return on investment (dimensionless): obtained by the ratio of gross income to the cost of investment for each treatment (unpublished data), d) profitability index (%): obtained by the ratio of net income and gross income.

All production input prices were surveyed in October 2017, coinciding with the beginning of the experiment. Labor costs were obtained from the Rural Workers' Union of Aquidauana, MS (Sindicato dos

Trabalhadores Rurais de Aquidauana-MS), with a daily rate of R\$ 35.00 for general field labor and R\$ 30.00 for drivers engaged in transport and harvest operations. Tractor-hour costs for tillage, harrowing, and field preparation were estimated at $\text{R\$ } 110.00 \text{ h}^{-1}$, excluding fuel. Input prices were obtained from local suppliers in the Aquidauana-MS region; poultry litter was priced at $\text{R\$ } 80.00 \text{ t}^{-1}$.

For the calculation of gross income, the unit market price was based on the average price of green cowpea ("caupi-hortaliça"), estimated at $\text{R\$ } 5.00 \text{ kg}^{-1}$. This reference price was adopted because commercial vegetable soybean production in Brazil still faces market limitations, mainly due to low consumer demand resulting from limited awareness of this form of soybean utilization. Therefore, this proxy price represents a conservative and practicable reference for economic comparison purposes.

The data were analyzed using analysis of variance (ANOVA) followed by Tukey's test ($p < 0.05$) with the SISVAR software (Ferreira, 2014). For evaluating the effects of poultry litter dosage, regression analysis was performed, and the highest-order polynomial equation was selected using Table Curve software.

3. Results and Discussion

The results in Table 1 indicate a significant difference among cultivars in the 100-immature grain weight and the number of pods per plant. Cultivar BRS 232 had the highest values, with 50.23 g for grain weight and 25.56 pods per plant.

In the interaction between the cultivars and poultry litter doses for the number of pods per plant, the BRS 232 cultivar outperformed the BRS 267 at doses of 6, 12, and 24 t ha^{-1} (Table 2). At 18 t ha^{-1} , the BRS 267 cultivar produced the highest number of pods.

Table 1. Plant height (PH), first pod insertion height (FPI), 100-immature grain weight (W100G), green pod yield (GPY), total yield of immature grains (TYIG), and number of pods per plant (NPP) in organically fertilized vegetable soybeans. Aquidauana-MS.

Cultivars	PH (cm)	FPI (cm)	W100G (g)	GPY (kg ha^{-1})	TYIG (t ha^{-1})	NPP
BRS 232	88.27 a*	8.37 a	50.23 a	4,114.75 a	2,431.60 a	25.56 a
BRS 267	82.20 a	77 a	39.61 b	5,108.76 a	1,892.69 a	17.35 b
F	1.558	0.712	79.99	1.93	2.45	18.26
CV(%)	16.13	28.99	7.47	43.83	45.00	25.31

* Means followed by the same letter in the column do not differ significantly according to Tukey's test at the 5% probability level.

Table 2. Number of pods per plant for two organically fertilized vegetable soybean cultivars in Aquidauana-MS.

Cultivars	Number of pods per plant			
	6	12	18	24
BRS 232	28.12 aAB	32.67 aA	20.35 bB	21.1 aB
BRS 267	13.37 bB	8.55 bB	30.87 aA	16.62 bB

* Means followed by the same lowercase letter in the column and the same uppercase letter in the row do not differ significantly according to Tukey's test at the 5% probability level. Number of pods per plant for two organically fertilized vegetable soybean cultivars in Aquidauana-MS.

For the BRS 232 cultivar, the quadratic regression model provided the best fit for plant height, first pod insertion height, 100-grain weight, green pod yield, and yield in relation to poultry litter doses incorporated into the soil (Figures 1A, 1B, 1C, 1D, and 1E). In contrast,

for the BRS 267 cultivar, no significant differences were observed for these traits, except for first pod insertion height, which increased linearly with poultry litter dose, and the 100-grain weight, which fitted a quadratic regression model (Figures 1B and 1C).

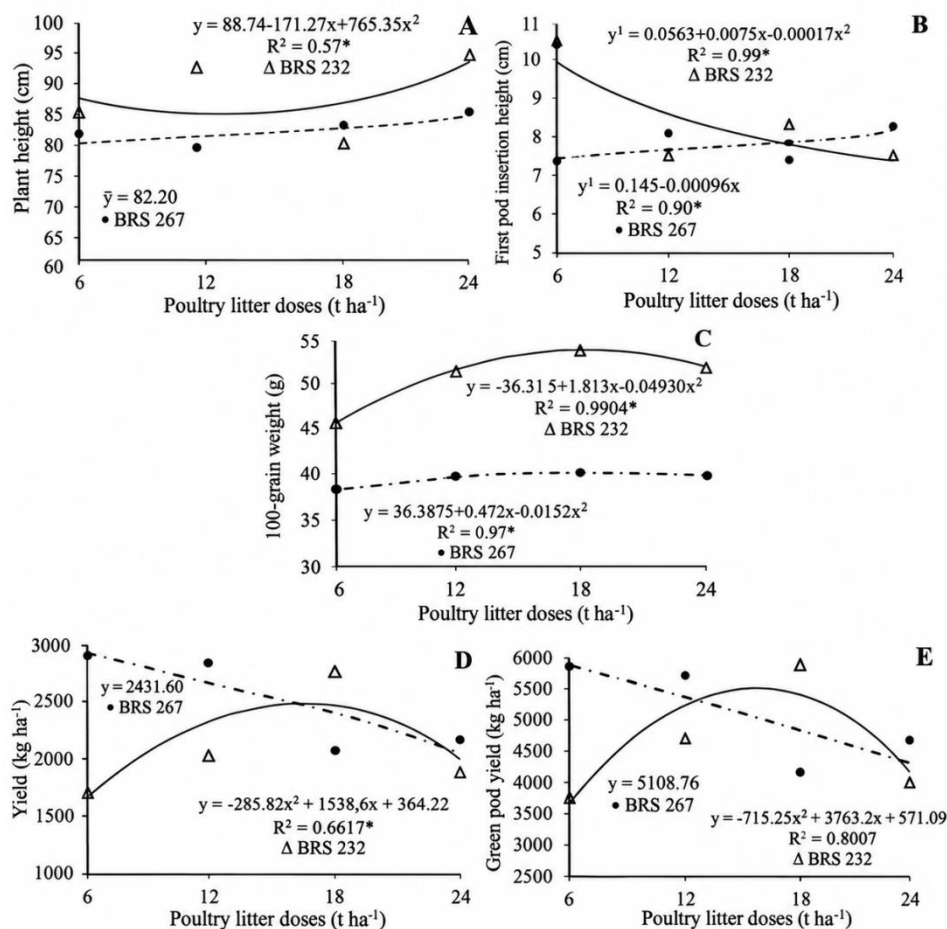


Figure 1. Plant height (A), first pod insertion height (B), 100-grain weight (C), green pod yield (D), and yield (E) of the soybean-vegetable cultivars BRS 232 and BRS 267, as a function of poultry litter doses. Aquidauana-MS, 2018.

For the BRS 232 cultivar, the maximum plant height was observed at the highest dose of 24 t ha⁻¹, reaching 82.74 cm, while the BRS 267 cultivar had an average height of 82.20 cm (Figure 1A). This behavior is consistent with the findings of Dhaliwal and Williams (2020) and Jiang et al. (2018b), who reported similar effects using mineral fertilizers. The nitrogen supplied by organic fertilizer enhanced chlorophyll biosynthesis, thereby promoting dry matter accumulation in the cultivars, comparable to the effects observed with mineral fertilizers.

At a poultry litter dose of 6 t ha⁻¹, the BRS 232 cultivar achieved the maximum first pod insertion height at 10.47 cm. However, this height decreased by 40.96% at the 24 t ha⁻¹ dose. For the BRS 267 cultivar, the highest first pod insertion height was recorded at the maximum poultry litter dose (Figure 1B). Cultivars with higher first pod insertion height facilitate manual harvesting and reduce pod-to-soil contact, with the

BRS 232 cultivar being particularly notable in this regard (Ribera et al., 2022). Given the lack of harvesters adapted for high-moisture grain harvesting in Brazil (Charlo et al., 2011), it is crucial to select cultivars that offer ergonomic benefits to producers.

The study focused on vegetable soybean production for commercial use and consumption, with pods harvested at the R6 maturation stage (Mozzoni and Chen, 2019). At this stage, the maximum 100-grain weights were 52.99 g at a poultry litter dose of 18.39 t ha⁻¹ for BRS 232, and 40.05 g at a dose of 15.53 t ha⁻¹ for BRS 267 (Figure 1C). The 100-grain weight is a critical parameter for cultivar comparison. Despite having a lower 100-grain weight, the BRS 267 cultivar is suitable for consumption as a soybean-vegetable due to its weight exceeding 25 g per 100 seeds, yellow hilum color, and adequate organoleptic characteristics in the immature stage (Ribera et al., 2024; Tobar-Tosse et al., 2015).

Seed yield variation can be attributed to the cultivars' genetic background and the multiple factors influencing this trait. Seed yield is not solely determined by genotype but results from a complex interaction between environmental factors and management practices (Van der Merwe et al., 2024). For the BRS 232 cultivar, green pod yield peaked at a poultry litter dose of 16.36 t ha⁻¹, reaching 5,710.54 kg ha⁻¹, with a subsequent decrease at higher doses. On average, the BRS 267 cultivar achieved a yield of 5,108.76 kg ha⁻¹ (Figure 1D). These findings are consistent with those reported by Jiang et al. (2018a). The lower yield of the BRS 267 cultivar is attributed to the production of smaller and lighter seeds (Yang et al., 2023).

Yield is a quantitative trait controlled by multiple genes, and nearly all agronomic characteristics influence seed production to varying degrees (Pandini et al., 2002). As expected, the yield of immature grains for the BRS 232 cultivar was maximized at a poultry litter

dose of 16.36 t ha⁻¹, reaching a maximum value of 2,613.53 kg ha⁻¹, followed by a decrease with increasing poultry litter doses. This result reflects the cultivar's superior performance in an organic production environment. In comparison, the average yield of immature grains for the BRS 267 cultivar was 2,431.60 kg ha⁻¹ (Figure 1E).

A significant interaction was observed between soybean-vegetable cultivars and poultry litter doses concerning the number of pods per plant. Dhakal et al. (2021) reported that taller plants tend to produce fewer pods compared to shorter plants. By comparison, the BRS 267 cultivar averaged 17.34 pods per plant, while the BRS 232 cultivar exhibited 34.27 pods per plant (Figure 2A). Both cultivars did not differ in terms of plant height, and this finding is consistent with values reported in the literature (Dhaliwal and Williams, 2020; Ribera et al., 2022).

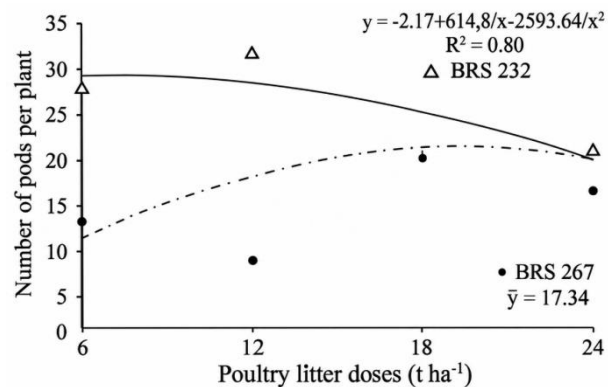


Figure 2. Number of pods per plant of soybean-vegetable cultivars BRS 232 and BRS 267, in relation to poultry litter doses. Aquidauana-MS, 2018.

The organic fertilizer derived from poultry litter proved to be effective in the production of soybean vegetables. Beyond nutrient release, organic fertilizers enhance the physical, chemical, and biological properties of the soil by promoting various microbiological processes related to mineralization (Alves et al., 2024), particularly in tropical environments where organic matter degradation occurs more rapidly and intensively.

Edamame represents a viable cropping option, particularly for small-scale farmers and urban producers, as it offers opportunities to increase income due to its high market value (Jiang et al., 2018a). Therefore, the study of economic efficiency becomes critical in soybean-vegetable research, especially considering the lack of information regarding economic aspects associated with poultry litter doses.

A significant interaction was observed among the analyzed variables between cultivars and poultry litter doses, indicating that the poultry litter doses are

dependent on the soybean-vegetable cultivars and vice versa (Figures 3A, 3B, 3C, and 4D).

For the BRS 232 soybean-vegetable cultivar, the highest gross income (GI) was achieved at a poultry litter dose of 6 t ha⁻¹, subsequently decreasing with higher doses up to 24 t ha⁻¹, where a maximum value of R\$ 13,800 was recorded. In contrast, the BRS 267 cultivar did not exhibit a regression fit, showing an average gross income of R\$ 10,883.46 (Figure 3A). This disparity can be attributed to the inclusion of poultry litter and transportation costs in the incremental analysis.

Regarding net income (NI), the BRS 232 soybean-vegetable cultivar yielded the highest amount of R\$ 4,900 at the poultry litter dose of 6 t ha⁻¹. Conversely, the BRS 267 cultivar did not fit a regression model, presenting an average net income of R\$ 1,492.69 (Figure 3B).

As observed in gross income, a similar trend was noted in net income, where the BRS 232 cultivar demonstrated superior performance. It is important to

highlight that production costs increased with higher doses, leading to a reduction in net income. This phenomenon occurred because, although yield increased with the application of the subsequent doses of 12, 18, and 24 t ha⁻¹, these increments were insufficient for economic viability. As a result, the increasing doses of poultry litter did not correspond to proportional increases in production, leading to a decrease in gross income.

The highest return rate (RR) of 1.70 for the BRS 232 soybean-vegetable cultivar was recorded at the dose of 6 t ha⁻¹. For the BRS 267 cultivar, no regression adjustment was observed, yielding an average return rate of 1.29. Thus, a higher return rate indicates a quicker financial return and a shorter time frame to recover investment costs associated with the activity. Consequently, the BRS 232 soybean-vegetable cultivar exhibited the highest return rate among the two cultivars

studied. This outcome may be associated with its physiological characteristic of semi-precocity compared to BRS 267, resulting in a shorter field duration and reduced exposure to various abiotic and biotic factors. Additionally, the poultry litter dose contributed to this finding, as the BRS 232 cultivar performed optimally at 6 t ha⁻¹, providing the best cost-benefit ratio.

The profitability index (PI) for the BRS 232 soybean-vegetable cultivar demonstrated optimal performance at the 6 t ha⁻¹ poultry litter dose, with an increase of 35%. In the case of the BRS 267 cultivar, the behavior exhibited was consistent with the other analyzed variables, resulting in an average profitability index of 5.76% (Figure 3D). Therefore, the BRS 232 cultivar is more favorable in terms of the profitability index, as a higher index indicates greater profit. This indicator is crucial for assessing the economic viability and sustainability of the activity.

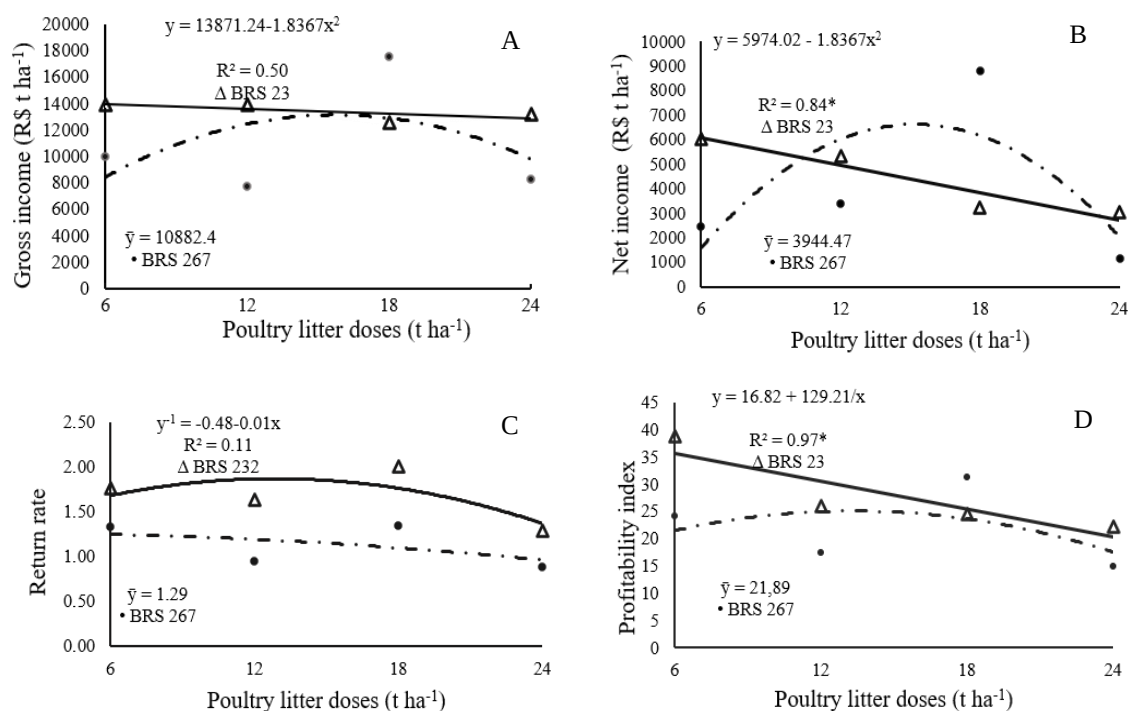


Figure 3. Economic efficiency study. Gross income (A), net income (B), return rate (C), and profitability index (D) of organically fertilized vegetable soybeans.

Among the poultry litter doses evaluated, lower rates proved to be the most cost-effective option, suggesting that adequate organic fertilization management is a promising strategy for optimizing vegetable soybean economic returns. However, the effectiveness of these fertilizers also depends on their chemical composition, mineralization rate, and nitrogen content (Oliveira et al., 2024). It is important to emphasize that the results found in this study are crucial, especially considering the high costs of inorganic fertilizers and environmental

pollution, which are significant concerns on a global scale. The use of poultry litter as fertilizer contributes to nutrient cycling due to its carbon and nutrient content, as well as its beneficial effects on soil physical properties and the increase in organic matter content (Nordi et al., 2022). However, it is crucial to monitor the application rates, as excessive dosages, as observed in this study, can increase costs and lead to a reduction in profitability.

4. Conclusions

The BRS 232 cultivar demonstrated superior agronomic performance at a poultry litter dose of 16.36 t ha⁻¹ and greater economic efficiency at 6 t ha⁻¹, which may be related to its early maturity.

Authors' Contribution

Laura Matos Ribera: original draft, experiment conduction, field analyses, data analysis, manuscript review and final writing. Roberto Carlos Seiji Sakissaka: experiment conduction, field analyses and data analysis. Mariana Dias Meneses: original draft and data analysis. Thatiane Nepomuceno Alves: original draft. Maiele Leandro da Silva: experiment conception, statistical analysis and final review.

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