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Productive performance of soybean (*Glycine max*) using lactofen as a growth regulator

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Abstract: The aim of this study was to evaluate the agronomic performance and productivity of soybean (Glycine max) using Lactofen as a growth regulator at different doses and phenological stages. The experiment was conducted at the Unifil School Farm in Londrina, Paraná, during the 2018/2019 growing season. The experimental design was a randomized complete block with five replications. The treatments consisted of three doses of the herbicide Lactofen: 0, 120, and 240 g L-1 a.i., and two phenological stages: V5 and V8. T1 controle 0 g L-1 i.a. de Lactofen, T2 240 g L-1 i.a. de Lactofen aplicado em V5, T3 240 g L-1 i.a. de Lactofen aplicado em V8, T4 120 g L-1 i.a. de Lactofen aplicado na V5 + 120 g L-1 i.a. de Lactofen aplicado em V8. Plots were 5.0 m long and 5.0 m wide, totaling 25.0 m2. Plant height, number of nodes, number of grains per pod, number of pods, weight of 1,000 grains, and yield in kg ha-1 were evaluated. Data were subjected to analysis of variance, and means were compared by Tukey's test at 5% probability of error. The doses of Lactofen 0, 120, and 240 g L-1 a.i. had little impact on soybean's productive components, showing no significant differences. The dose of 240 g L-1 a.i. applied at V8 resulted in higher productivity compared to the other treatments.

Palavras-chave: Yield, Dosage, Phytotoxicity, Protox.

Desempenho produtivo de soja (*Glycine max*) utilizando lactofen como regulador de crescimento

Resumo: O estudo teve como objetivo avaliar o desempenho agronômico e a produtividade da cultura da soja (*Glycine max*) utilizando o Lactofen como regulador de crescimento em diferentes doses e estádios fenológicos. O experimento foi conduzido na Fazenda Escola Unifil em Londrina, Paraná, durante a safra 2018/2019. O delineamento experimental foi em blocos casualizados, com cinco repetições. Os tratamentos consistiram em três doses do herbicida Lactofen (0, 120 e 240 g L^{-1} i.a) e dois estádios fenológicos (V5 e V8), sendo T1 controle 0 g L-1 i.a. de Lactofen, T2 240 g L-1 i.a. de Lactofen aplicado em V5, T3 240 g L-1 i.a. de Lactofen aplicado em V8, T4 120 g L-1 i.a. de Lactofen aplicado na V5 + 120 g L-1 i.a. de Lactofen aplicado em V8. As parcelas tinham 5,0 m de comprimento por 5,0 m de largura, totalizando 25,0 m^2. Foram avaliados a altura das plantas, o número de nós, o número de grãos por vagem, o número de vagens, o peso da massa de 1.000 grãos e a produtividade em kg ha-1. Os dados foram submetidos à análise de variância e as médias foram comparadas pelo teste de Tukey a 5% de probabilidade de erro. As doses de Lactofen (0, 120 e 240 g L^{-1} i.a) tiveram pouco impacto nos componentes produtivos da soja, não apresentando diferenças significativas. No entanto, a dose de 240 g L^{-1} i.a aplicada no estádio V8 resultou em maior produtividade em comparação com os demais tratamentos.

Key-words: Produtividade; Dose; Fitotoxidade; Protox.

1. INTRODUCTION

Soybean (*Glycine max* [L.] Merril) originated in China and is known for its high protein content and a balanced amino acid profile compared to other grains (CÂMARA, 2011). Initially cultivated for human consumption (MUNDSTOCK & THOMAS, 2005), soybean is now widely used in animal feed and oil extraction, which is widely consumed by a large portion of the population (GONDIN, 2019), making it of great socio-economic importance due to job creation and overall country development (FUZZO, 2015).

Brazil is the second-largest producer of soybeans, behind only the United States. It is also recognized as the largest exporter of soybeans, accounting for 42.5% of exports, followed by the United States with 39.1% (BHEEMANAHALLI et al., 2022.). According to the National Supply Company (CONAB, 2019), the planted area of soybeans showed significant growth compared to the 17/18 harvest, reaching 35,793 million hectares, reflecting an increase of 1.8% in the 18/19 harvest, with an expected yield of 3,300 kg ha^{-1}.

It is estimated that by 2050, the world population will reach 9 billion people, and if consumption continues at the same level, it will be necessary to produce about 60% more food to meet this demand (UN, 2015). One of the available alternatives to meet this need is the use of genetic improvement programs, which aim to produce more productive and disease-resistant cultivars (PÍPOLO et al., 2007). Plant architecture also significantly influences productivity, as some structures hinder the absorption of phytosanitary products and solar radiation, directly affecting productivity (DEBORTOLI et al., 2012).

The use of growth regulators is an alternative for controlling soybean structure (GALLON et al., 2016; LEITE; CRUSCIOL & SILVA, 2011), as compact cultivars tend to redistribute their resources better, allowing for higher yields (LIU et al., 2010). Besides regulators, other products can be used (GALLON et al., 2016; LEITE et al., 2011), such as Lactofen, a molecule that, in addition to its herbicidal action, can also structurally modify soybean plants, increasing productivity (FOLONI et al., 2018).

Lactofen's mechanism of action involves inhibiting protoporphyrinogen oxidase (PROTOX), leading to the accumulation of photodynamic compounds, which, in the presence of light and oxygen, result in the formation of singlet $^1O2$, causing lipid peroxidation, membrane rupture, and ultimately, cell death (CARVALHO, 2013). Its phytotoxicity results in the breaking of apical dominance, leading to shorter plants and increased branching (SOARES, 2013).

According to a study by Arruda (2014) using the BMX Ativa cultivar, the dose of 240 g L^{-1} a.i. of Lactofen resulted in a significant increase of 396.6 kg ha-1 in yield. Other positive aspects obtained with the use of Lactofen were reduced lodging and plant height in the BRS 317 cultivar. The lodging score with a dose of 0 g L^{-1} a.i. was 2.6, while with a dosage of 240 g L^{-1} a.i., it was 1. As for plant height, with a dose of 0 g L-1 a.i., soybean reached 109 cm, while with a dosage of 240 g L^{-1} a.i., the average was 93 cm (FOLONI et al., 2014). However, a study conducted with soybean planting in Londrina and Ponta Grossa showed that the use of Lactofen significantly reduced yield in all tested cultivars (FOLONI et al., 2016). Similarly, in a study by Heiffig (2006), the use of the same herbicide on the Conquista soybean cultivar resulted in a reduction in the weight of 1,000 grains and crop yield.

Based on the above, it is not yet possible to conclude the real effectiveness of Lactofen in increasing soybean yield; therefore, further studies are needed to confirm this fact. This study aims to evaluate the agronomic performance and yield of soybean as affected using Lactofen at different doses and phenological stages.2.

2. MATERIAL AND METHODS

The experiment was conducted at the Unifil School Farm (Centro Universitário Filadélfia), located in Londrina, PR, Brazil (23°23'20" S, 51°10'29" W, altitude 546 m). The study was implemented during the 2018/2019 growing season.

The soil in the experimental area is classified as Dystroferric Red Latosol with undulating relief and slopes ranging from 0.5% to 1% (SANTOS, 2018). According to Köppen's classification, the climate is Cfa (humid subtropical climate) (IAPAR, 2000), characterized by hot summers with average temperatures above 22 °C and concentrated rainfall during this period. Winters have average temperatures below 18 °C, with low frost occurrence. This type of climate does not have a well-defined dry season (MELO, 2007).

The experimental design used was randomized complete blocks (RCB) with 5 blocks, 4 treatments, and 5 replications, totaling 20 plots. Each plot measured 5 meters wide by 5 meters long (25 m^2), totaling 500 m^2 of total experimental area. The spacing used was 0.45 m between plants with 13 plants per linear meter throughout the experiment, resulting in a population of 288,888 plants per ha^{-1}.

The herbicide NAJA, with Lactofen as the active ingredient, was applied at different doses: 0 g L-1 a.i. and 240 g L^{-1} a.i. at two phenological stages, V5 and V8, and the combination of V5+V8. Therefore, the experiment used the following treatments: T1 control 0 g L^{-1} a.i. of Lactofen, T2 240 g L^{-1} a.i. of Lactofen applied at V5, T3 240 g L^{-1} a.i. of Lactofen applied at V8, T4 120 g L^{-1} a.i. of Lactofen applied at V5 + 120 g L-1 a.i. of Lactofen applied at V8.

The cultivar used in the experiment was Coodetec 2618 IPRO, with a relative maturity group of 6.1, early cycle, highly demanding in fertility, moderately resistant to root-knot nematodes *M. incognita*, resistant to root-knot nematodes *M. javanica*, and moderately resistant to lodging. The recommended average population was 288,000 plants ha^{-1}, with a weight of 1,000 grains of 180 g.

On December 10, 2018, the herbicide Gramoxone® 200 (Paraquat) was applied at a rate of 2 L ha^{-1} to control weeds.

The seeds were treated with Standak Top® (Pyraclostrobina tiofanato and Methyl-fipronil) at a rate of 200 ml p.c.* ha^{-1} and inoculated with the inoculant Masterfix (Bradyrhizobium) at a rate of 300 grams per 50 kg of seed.

Sowing was done on December 18, 2018, using the no-tillage system. The stand was established with 13 plants per linear meter as recommended by the manufacturer. According to the chemical analysis, the required fertilizer amount was obtained and placed directly in the planting furrow. The formulation used was 02–20–18 at a rate of 300 kg ha^{-1}.

On January 12, 2019, Glyphosate Nortox (Glyphosate) at a rate of 2 L ha^{-1} + Select 240 EC (Clethodim) at a rate of 0.4 L ha^{-1} + Assist® (Mineral oil) at a rate of 0.4 L ha^{-1} were applied to control weeds for crop development.

On March 8, 2019, the fungicide Sphere Max (Trifloxystrobin + Cyproconazole) at a rate of 0.2 L ha^{-1} was applied preventively for Asian soybean rust and other phytopathogenic fungi. Along with the fungicide, the insecticide Connect (Imidacloprid + Beta-cyfluthrin) at a rate of 0.5 L ha^{-1} was applied to control brown stink bugs (*Euschistus heros*).

After the plants reached the V5 stage, Lactofen was applied at a dose of 100% (240 g L^{-1} a.i.) in treatment T2 and 50% (120 g L^{-1} a.i.) of the dose in treatment T4. When the crop reached the V8 stage, Lactofen was applied at a dose of 100% (240 L^{-1} a.i.) in treatment T3, and the other 50% (120 g L^{-1} a.i.) of the dose in treatment T4.

When the plants reached the reproductive stage R7, with pods in the yellowing process, evaluations began. The variables evaluated were: plant height; number of reproductive nodes; number of pods; and number of grains per pod. For the evaluations, 5 plants per plot were randomly selected.

For plant height, the measurement was from the soil to the apical meristem; for the evaluation of the number of reproductive nodes, the same plants were used, and the number of reproductive nodes was counted; for the number of pods, the same plants as in the other evaluations were used. All pods were counted for evaluation. The pods were then opened, and the grains were counted to obtain an average number of grains per pod.

When the plants reached the R8 stage, harvesting of 2 linear meters of plants from each plot was initiated to obtain the weight of 1,000 grains. The yield of each treatment was estimated in kg ha^{-1}.

The data obtained were analyzed using the R program with the RStudio interface, and the means were compared using Tukey's test at 5% probability of error.

3. RESULTS AND DISCUSSION

The low variation in structural aspects and the lack of statistical differentiation among soybean plants can be explained by the late sowing of the Coodetec 2618 IPRO cultivar, which hindered its development, not allowing it to express its full productive potential. According to Amorim et al. (2011), as sowing is delayed, plants tend to be shorter, with delayed flowering, consequently leading to a decrease in production.

During the experiment period, the total rainfall was 379.21 mm, with average temperatures of 24.4 °C (Figure 1). The average temperatures are classified as normal, but the rainfall is considered low according to Farias, Nepomuceno, and Neumaier (2007), who consider normal precipitation for good crop yield to be between 450 and 800 mm, distributed throughout the soybean cycle. The precipitation level during most of the plant cycle hindered its development (PEIXOTO et al., 2000).

Table 1 shows the results for plant height. There were no significant differences, with the highest average found in treatment T1 (0 g L^{-1} a.i.) at 58.32 cm in length, and the lowest average was 56.84 cm in treatment T2 (240 g L^{-1} a.i. in V5). In contrast to this study, Buzzello (2010) and Barbosa (2023) observed a significant reduction in soybean plant height when Lactofen was applied as a growth regulator.

Similarly to plant height, the use of Lactofen did not significantly affect the number of nodes per plant. The highest average was in treatment T3 (240 g L^{-1} a.i. in V8) with 16.28 nodes, and the lowest average was in treatment T1 (0 g L^{-1} a.i.) with 14.04 nodes. A similar result was also found by Soares (2016) in his study with Lactofen in soybeans in the municipality of Patos de Minas, MG.

Although the variation in the number of nodes was low, it can affect the final productivity, as it is an important productive component that influences the number of pods and the number of grains per pod (SETIYONO et al., 2007).

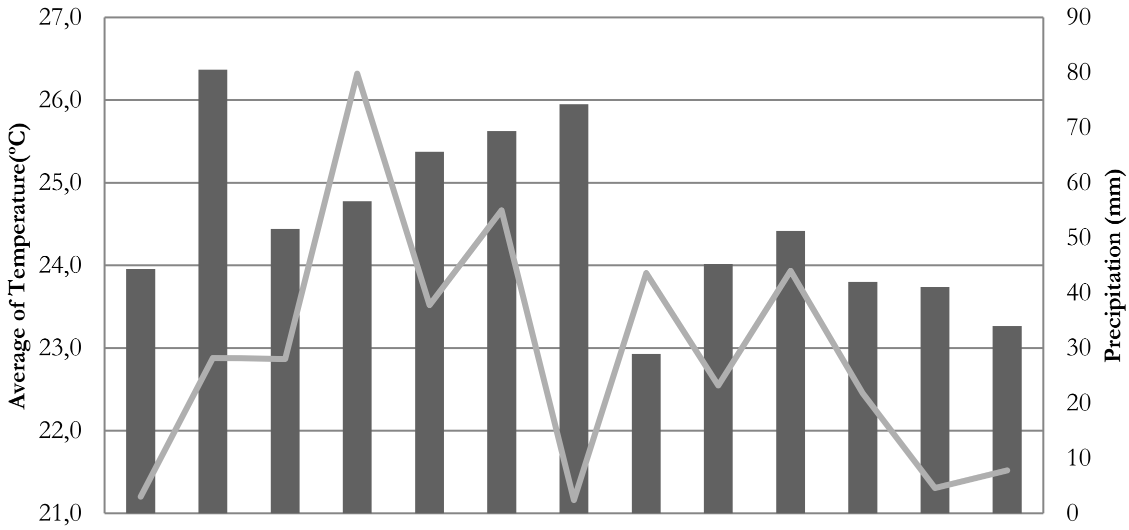

Figure 1 – Mean precipitation and temperature during the experiment.

Table 1 – Table of the mean height and number of nodes in soybean plants as a function of different doses of Lactofen and different phenological stages (T1 0 g $^{L-1}$ a.i., T2 240 g $^{L-1}$ a.i. in V5, T3 240 g $^{L-1}$ a.i. in V8, T4 120 g $^{L-1}$ a.i. in V5 + 120 g $^{L-1}$ a.i. in V8).

Treatments	Plant Height	Nº of nodes plants^{-1}
DOSE LACTOFEN	----- cm -----	
T1	58,32 a	14,04 a
T2	56,84 a	14,72 a
T3	58,20 a	16,28 a
T4	57,28 a	14,68 a
CV(%)	9,36	9,61

Source: author (2019).

Table 2 shows the results for the variable number of grains per pod. There were no significant differences, with the highest average found in treatment T3 (240 g L^{-1} a.i. in V8) at 2.25, while the lowest average was in treatment T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8) at 2.05 grains per pod. Similar results were also found by Braz et al. (2010) in their study with Lactofen for soybean desiccation.

Table 2 – Table of the averages of the productive components and yield of soybean as a function of different doses of Lactofen and different phenological stages (T1 0 g $^{L-1}$ a.i., T2 240 g $^{L-1}$ a.i. in V5, T3 240 g $^{L-1}$ a.i. in V8, T4 120 g $^{L-1}$ a.i. in V5 + 120 g $^{L-1}$ a.i. in V8).

Treatments	Nº grains per pod	Nº of pods	PMS	Productivities
DOSE LACTOFEN	nº.plant^{-1}	nº.plant^{-1}	---- g ----	Kg ha^{-1}
T1	2,08 a	49,48 a	131,3 a	3890,48 ab
T2	2,12 a	48,56 a	127,9 a	3798,60 ab
T3	2,25 a	56,24 a	127,7 a	4664,81 a
T4	2,05 a	47,68 a	131,6 a	3680,07b
CV(%)	5,07	12,74	5,88	11,87

Source: author (2019).

Table 2 also shows the results for the evaluation of the number of pods per plant. There were no statistically significant differences, with the highest averages in treatment T3 (240 g L^{-1} a.i. in V8) at 56 pods, while the treatment with the lowest average was T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8) at 47.68 pods per plant. Barbosa (2023), in his study with Lactofen at different doses and phenological stages, although doses in later periods reduced the number of pods, did not find a significant difference between treatments.

Table 2 presents the results for the variable weight of 1,000 grains. There were no statistically significant differences, with treatment T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8) achieving the highest average at 131.6 g, while treatment T3 (240 g L^{-1} a.i. in V8) had the lowest average at 127.7 g.

Unlike the other evaluated attributes, the productivity results (Table 2) were significant. Treatment T3 (240 g L^{-1} a.i. in V8) showed the best results (4664.81 kg ha^{-1}), but there was no significant difference compared to the control T1 (0 g L^{-1} a.i.) with 3890.48 kg ha^{-1} and treatment T2 (240 g L^{-1} a.i. in V5) with 3798.60 kg ha-1. However, treatment T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8) had a statistically lower average yield compared to treatment T3 (240 g L^{-1} a.i. in V8) with 3680.07 kg ha^{-1}. Similar results were found by Barros et al. (2000), who applied Lactofen to the soybean variety cv. EMGOPA 316 and did not observe a significant difference between the Lactofen treatment and the control (3,664 kg ha^{-1} and 3,578 kg ha^{-1}, respectively).

According to the Department of Rural Economics (DERAL) and Agricultural Market Information System (SIMA), the average price of a 60 kg bag of soybeans on October 4, 2019, in the state of Paraná, Brazil, was R$ 75.25, and the average price of a liter of the herbicide NAJA was R$ 63.55. Thus, treatment T3 (240 g L^{-1} a.i. in V8), which had an average yield of 4,664.81 kg ha^{-1}, resulted in a gross income of R$ 5,850.44 ha^{-1} after deducting the cost of the product. Treatments T1 (0 g L^{-1} a.i.) and T2 (240 g L^{-1} a.i. in V5) had an income of R$ 4,881.25 ha^{-1} and R$ 4,702.42 ha^{-1}, respectively, with the worst-performing treatment being T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8) with an income of R$ 4,551.87 ha^{-1}.

Treatment T3 (240 g L^{-1} a.i. in V8), when compared to the control T1 (0 g L^{-1} a.i.), showed a gain of R$ 969.19, representing 19.85% more gross income. In treatment T2 (240 g L^{-1} a.i. in V5), a loss of R$ 1,148.02, representing 19.6% less gross income, was observed compared to treatment T3 (240 g L^{-1} a.i. in V8). Meanwhile, in treatment T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8), a loss of R$ 1,298.57, representing 22.1% less profit, was observed.

4. CONCLUSIONS

The use of the herbicide lactofen at all tested doses did not significantly alter the characteristics of soybeans such as plant height, number of nodes, number of grains per pod, number of pods, and 1,000-grain weight.

Treatment T3 (240 g L^{-1} a.i. in V8) showed better productivity compared to treatment T4 (120 g L^{-1} a.i. in V5 + 120 g L^{-1} a.i. in V8).

The dose of 240 g L^{-1} a.i. applied at the V8 phenological stage resulted in higher gross income for the producer, indicating that Lactofen, when applied at the correct dose and phenological stage, becomes profitable.

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