OLIVIEIRA, P. L. S.; BEZERRA, A. C.. T. P.; BORGES, C. P.; MATTOS, C. G. O.; FERREIRA, D. K. B.; COSTA NETTO, A. P. Effect of applying mixed organomineral fertilizer as a biostimulant on soybean yield. **Revista de Agricultura Neotropical**, Cassilândia-MS, v. 11, n. 2, e8303, Apr./June, 2024. ISSN 2358-6303. DOI: https://doi.org/10.32404/rean.v11i2.8303.

Effect of applying mixed organomineral fertilizer as a biostimulant on soybean yield

Pedro Luid de Sousa Olivieira[1], Aracy Camilla Tardin Pinheiro Bezerra[1], Cássio do Prado Borges[1], Carlos Gabriel Oliveira Mattos[1], Deise Kelle Barbosa Ferreira[1], Antônio Paulino da Costa Netto[1]

[1] Universidade Federal de Jataí, Jataí, Goiás, Brasil. E-mail: luid_oliveira@discente.ufj.edu.br, aracycamilla@hotmail.com, pradocassio297@gmail.com, cgabriel86agro@discente.ufj.edu.br, deise.kelle@discente.ufj.edu.br, apcnetto@ufj.edu.br

Received: 05/10/2023; Accepted: 29/04/2024.

ABSTRACT

Although soybean is economically one of the main agricultural products in the national and world scenario, it is still needed to increase its grain yield. Therefore, this study aimed to evaluate the effect of applying mixed organomineral fertilizer (OMF) at different doses and at two phenological stages on soybean yield. The experiment was conducted in the experimental area of the Federal University of Jataí, in the state of Goiás, and was installed under a no-till system (NTS). The experimental design used was randomized blocks arranged in a 4 x 2 + 1 factorial scheme, consisting of four doses of OMF, applied at two phenological stages and one additional control. The following OMF doses were evaluated: 0.5 kg ha^{-1}, 1 kg ha^{-1}, 1.5 kg ha^{-1}, and 2 kg ha^{-1}, at two reproductive stages: R_3 and R_5, and the additional control. The experiment consisted of three blocks. Each plot had a useful area of 16.2 m². The agronomic parameters assessed were plant height (m), first pod insertion height (m), number of pods per plant, number of grains per pod, 1000-grain mass (g), and grain yield (kg ha^{-1}). The application of OMF as a biostimulant to soybean crops led to an increase in the first pod insertion height and the number of pods per plant; it did not lead to higher yields; however, when applied at phenological stage R_5, higher yields were observed compared to application at R_3.

Keywords: *Glycine max*, Doses, Phenological stages.

Efeito da aplicação de adubo organomineral misto como bioestimulante na produtividade da soja

RESUMO

Embora a soja seja economicamente um dos principais produtos agrícolas no cenário nacional e mundial, ainda se busca aumentar sua produtividade. Assim, objetivou-se, com o presente trabalho, avaliar o efeito da aplicação do adubo organomineral misto (AOM), em diferentes doses e em dois estádios fenológicos, na produtividade da soja. O experimento foi conduzido na área experimental da Universidade Federal de Jataí, no estado de Goiás, e foi instalado sob Sistema de Plantio Direto (SPD). O delineamento experimental utilizado foi de blocos casualizados em esquema fatorial 4 x 2 + 1, composto por 4 doses do AOM, aplicadas em 2 estádios fenológicos e 1 testemunha adicional. Foram avaliadas as seguintes doses do AOM: 0,5 kg ha^{-1}; 1 kg ha^{-1}, 1,5 kg h^{-1} e 2 kg h^{-1}, em dois estádios reprodutivos: R_3 e R_5, e a testemunha adicional (tratamento controle). O experimento foi composto por 3 blocos. Cada parcela foi constituída por área útil de 16,2 m². Os parâmetros agronômicos avaliados foram: altura de planta (m), altura de inserção de primeira vagem (m), número de vagens por planta, número de grãos por vagem, massa de mil grãos (g) e produtividade (kg ha^{-1}). A aplicação do AOM, como bioestimulante na cultura da soja, proporcionou incremento na altura de inserção de primeira vagem e no número de vagens por planta; não proporcionou maior produtividade, no entanto, quando aplicada no estádio fenológico R_5 foi observada maior produtividade em comparação com a aplicação em R_3.

Palavras-chave: *Glycine max,* Doses, Estádios fenológicos.

1. Introduction

Soybeans are economically one of the main agricultural products in the national and world scenario. In Brazil, soybean is one of the main crops in terms of area and volume of production. For this reason, over the years, there have been attempts to increase soybean production in the country by increasing the area planted and/or the maximum yield per area (Oliveira and Ferreira, 2020). Various technologies can be used to increase yield, including more resistant and productive cultivars, high quality seeds, assertive soil management, plant protection treatments, agricultural mechanization technologies, and precision agriculture (Moterle et al., 2008; Ferrazza et al., 2020; Kovalski et al., 2020).

However, the occurrence of climatic adversities, such as the occurrence of water deficit, associated with the appearance of new biological elements that are enemies of the crop, as well as the adoption of poorly designed or poorly positioned management measures, are some of the factors that negatively interfere with the soybean production system, thus affecting its grain yield (Francisco and Câmara, 2013; Cavalcante et al., 2020).

In this context, one of the main bottlenecks that can occur in the soybean cultivation system is the abortion of flowers and pods, which, although a natural process, can be influenced by several factors, such as environmental stresses: water deficit, high temperatures, and nutritional deficiency (Silva et al., 2017; Neumaier et al., 2020).

Given their positive physiological effects, one of the alternatives to mitigate this problem and increase soybean yield is to apply biostimulants to the crop. Biostimulants are mixtures of two or more plant bioregulators comprising amino acids, minerals, vitamins, plant extracts, hormones, and nutrients (Cavalcante et al., 2020).

They provide higher grain yield, stimulate growth, reduce the consequences induced by environmental stress, and increase crop yield, so they stand out as promoters of yield optimization, offering a potentially new approach (Kocira, 2019; Oliveira et al., 2022; Yakhin et al., 2017). Its use has grown mainly because it is an alternative to mineral fertilizers and an environmentally friendly option (Galindo et al., 2019).

The mixed organomineral fertilizer (OMF) used in this study is a foliar fertilizer containing nitrogen, phosphorus, potassium, secondary macronutrients, and micronutrients, which provides the plant with rich and diversified complementary nutrition. In addition, it promotes the biosynthesis of natural auxins, as it provides large amounts of tryptophan, their precursor. It also promotes cell division and expansion due to the Ascophyllum nodosum extract, which is rich in active ingredients with auxin and cytokinin-like activity.

In this context, applying OMF could mitigate possible stresses especially the abortion of flowers and pods that can occur during the soybean cycle and, indirectly, increase crop yield. Other research has obtained positive results with the use of bioregulators and OMF as biostimulants in other crops (Castro et al., 2019; Torsian et al., 2020; Costa et al., 2022) and in the soybean crop, however, their effects vary depending on the time of application, dose, and cultivar used (Cavalcante et al., 2020; Kovalski et al., 2020; Araújo et al., 2021; Meyer et al., 2021; Cavalcante et al., 2022).

The present study aimed to evaluate the effect of applying OMF as a biostimulant at different doses and two phenological stages on soybean grain yield.

2. Material and Methods

The experiment was conducted in the experimental area of the Federal University of Jataí, in the state of Goiás. The climate of the region, according to the Köppen climate classification, is tropical rainy, Aw-type, with dry winters from April to September and hot, rainy summers from October to March (Mariano and Rocha, 2016). Figure 1 shows the climatic data for rainfall (mm) and temperature (ºC) for 2022 during the experiment.

The soil in the experimental area is classified as Latossolo Vermelho Distroférrico, with a very clayey texture (Santos et al., 2018), and its chemical characteristics are shown in Table 1.

The experiment was set up under a no-till system on November 11, 2021. 400 kg ha^{-1} of formulated 02-20-18 (NPK) and 185 kg ha^{-1} of monoammonium phosphate (MAP) were applied at the sowing furrow. The experimental design was randomized blocks arranged in a 4 x 2 + 1 factorial scheme, consisting of four OMF doses used as a biostimulant, applied at two phenological stages, R_3 and R_5, and one additional control (control treatment). The experiment was divided into three blocks, each consisting of eight treatments plus the control treatment. Each plot had a useful area of 16.2 m², 6 m long, with six rows of soybeans spaced 0.45 m apart, with 12 plants per meter.

The variety used was BMX Bonus IPRO. This cultivar belongs to the relative maturity group 7.9, with medium/high soil fertility requirements, excellent initial development, indeterminate growth habit, tall size, medium resistance to target spot, and medium branching. At the start of the vegetative stage, 0.3 L ha^{-1} of Aproach Prima® fungicide and 0.1 L ha^{-1} of Seizer® insecticide were applied. 150 liters of mixture were used for all applications of these products. On December 20, 2021, 0.5 L ha^{-1} of Agrumax MZ®, Fosfik Cu®, Nov@®, and Fylloton® were applied as crop treatments to the soybeans.

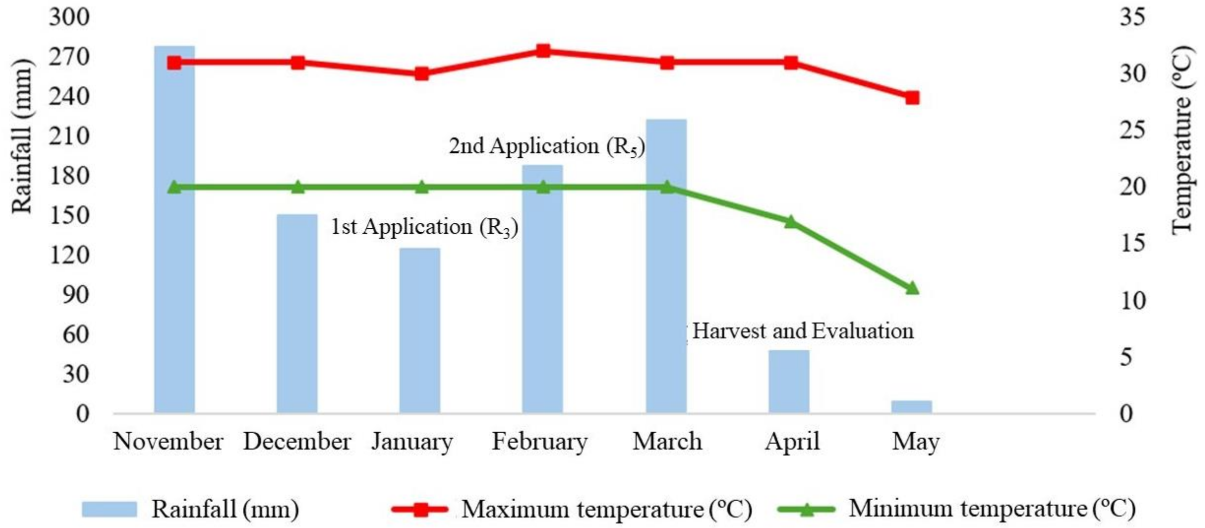

Figure 1. Rainfall (mm) and maximum and minimum temperatures (ºC) from November to May (first soybean crop season 2021/2022 in the municipality of Jataí GO). The bars represent monthly rainfall. November: sowing; January: first application (R_3) of mixed organomineral fertilizer (OMF); February: second application (R_5) of OMF; April: harvest. Source: INMET, 2023.

Table 1. Results of the soil chemical analysis in the experimental area where the treatments of mixed organomineral fertilizer (OMF), used as a biostimulant, were applied to the soybean in the 2021/2022 crop season, Jataí-Goiás.

pH	O.M	P	K	Ca	Mg	Al	S
$CaCl_2$	$g.dm^{-3}$	$mg.dm^{-3}$	$cmol_c.dm^{-3}$	$mg.dm^{-3}$			
5.6	36.0	3.7	0.3	3.8	1.6	0.0	3.7
H+Al	CEC	V	B	Zn	Fe	Mn	Cu
$cmolc.dm^{-3}$		(%)	$mg.dm^{-3}$				
3.6	9.3	60.9	0.3	1.0	26.0	57.1	14.1

pH: Soil pH. O.M: Organic Matter. P: Phosphorus. K: Potassium. Ca: Calcium. Mg: Magnesium. Al: Aluminum. S: Sulphur. H+Al: Potential Soil Acidity. CEC: Cation Exchange Capacity. V: Base Saturation. B: Boron. Zn: Zinc. Fe: Iron. Mn: Manganese. Cu: Copper.

The mixed organomineral fertilizer (OMF) used contains the macronutrients nitrogen (N in nitric form - 6.3%, N in ammoniacal form - 4.5%, N in amide form - 2.2%), potassium (K_2O water-soluble-21%), phosphorus (P_2O_5 water-soluble - 8%), magnesium (Mg water-soluble - 2%) and sulfur (S water-soluble - 5.5%), the micronutrients iron (chelated Fe EDDHA - 0.2%), zinc (Zn water-soluble - 0.1%), copper (chelated Cu EDTA - 0.05%), and boron (B water-soluble - 0.03%), as well as an amino acid complex containing glutamic acid and tryptophan, and *Ascophyllum nodosum* seaweed extract. Table 2 describes the treatments used in the experimental area.

A total of two applications of the product were made. The first application was conducted on January 27, and the second on February 10, 2022. The applications were conducted using a CO_2-pressurized knapsack sprayer and a constant working pressure of 3 bars, equipped with a 4-nozzles boom spaced 0.5 m apart and a spray volume of 200 L ha^{-1}.

The three central rows of each plot were harvested on April 2, 2022. The plants were counted, stored in fiber bags, and labeled according to the plot identification during harvesting. These plants were then threshed to separate the grains from the pods for weight and moisture measurement. In addition to harvesting the three central rows, a random harvest of five plants from each plot was conducted on April 3, 2022, to assess agronomic characteristics.

Also, in April 2022, plant height (m), first pod insertion height (m), number of pods per plant, number of grains per plant, 1000-grain mass (g), and grain yield (kg ha^{-1}) were evaluated. Plant height and first pod insertion height were measured using a graduated tape measure, and the number of pods per plant and the number of grains per plant were counted. The 1000-grain mass (g) was calculated according to the Seed Analysis Rule (Brasil, 2009), and the grain yield, corrected to 13%, was calculated and extrapolated using data from the experiment, expressed in kg ha^{-1}.

The agronomic traits were subjected to analysis of variance (ANOVA) using the F test at 5% significance. The means were compared using the Tukey test at 5% significance using the Rbio software (Bhering, 2017). The Microsoft Excel (2016) program was used to create the graphs.

Table 2. Treatments composed of doses of mixed organomineral fertilizer (OMF), used as a biostimulant, applied at two phenological stages, R_3 and R_5, in the soybean crop in the 2021/2022 crop season.

Treatments	Dose (kg ha^{-1})	Phenological
Treatment 1	0.5	R_3
Treatment 2	1.0	
Treatment 3	1.5	
Treatment 4	2.0	
Treatment 5	0.5	R_5
Treatment 6	1.0	
Treatment 7	1.5	
Treatment 8	2.0	

3. Results and Discussion

According to the results in Table 3, the interaction between the doses and application at different phenological stages influenced the number of pods per plant and 1000-grain mass. The application at different phenological stages had an isolated effect on grain yield. There was no isolated effect of doses for any of the variables analyzed. The results of the significant interaction between the OMF doses and the application at different phenological stages for the number of pods per plant are shown in Table 4.

Although there was an influence of the interaction between the factors studied on the number of pods per plant, there was no significant difference, using the Tukey test, between the means of this variable in the application at two phenological stages, R_3 and R_5, with the values of the number of pods per plant resulting from the development of the cultivar itself. According to the climate graph (Figure 1), the weather conditions favored the normal development of the crop. The regression for the OMF doses in each phenological stage was not presented because it was not statistically significant either.

Araújo et al. (2021) conducted a study on the action of the biostimulants Proggib®, Stimulate®, and Biozyme®, applied at phenological stages R_1 and R_2 on the commercial soybean cultivars HO Cristalino, M 8644 IPRO, TMG 2185 IPRO, NS 7901 IPRO, M 7739 IPRO, and CZ48B32 IPRO, some of them (M 8644 IPRO, CZ48B32 IPRO, HO Cristalino, and TMG 2185 IPRO) had statistically equal average numbers of pods per plant, with an overall average of 92.7 pods per plant.

Similarly, Kovalski et al. (2020), evaluating different managements with biostimulant products (2.4-D, Progibb, Biofran, and Internode) on seven soybean cultivars, found no variations between the managements applied to the five cultivars evaluated (TMG 2185 IPRO, M 8372 IPRO, IMA 84114 RR, M 7110 IPRO, and IMA 831 IPRO), with an overall average of 68.04 pods per plant, and the NS 7667 IPRO cultivar, with no application of products, had the highest value of NPP. Cavalcante et al. (2020) also found no significant effect on the number of pods per soybean plant due to applying different biostimulants, including amino acids, algae extract, fulvic acids, phytohormones, and nutrients.

Table 3. Summary of the analysis of variance for plant height (HGT), first pod insertion height (HGT. INS.), number of pods per plant (NPP), number of grains per plant (NGP), 1000-grain mass (TGM), and grain yield (YIEL) according to the application of doses (D) of mixed organomineral fertilizer (OMF), used as a biostimulant, at different phenological stages (PS) in the soybean crop.

Agronomic characteristics		HGT (m)	HGT. INS. (m)	NPP	NGP	TGM (g)	YIEL (kg ha^{-1})
Source of variation	DF				MS		
Block	2	89.53^{ns}	17.16^{ns}	3.22^{ns}	27.47^{ns}	44.61*	8,640.12^{ns}
Dose (D)	3	8.53^{ns}	0.43^{ns}	0.91^{ns}	29.80^{ns}	2.63^{ns}	27,108.08^{ns}
PS	1	20.35^{ns}	10.01^{ns}	0.39^{ns}	27.47^{ns}	31.65*	418,387.00*
D x PS	3	6.81^{ns}	12.96^{ns}	49.30*	161.52^{ns}	55.05*	86,257.08^{ns}
Ad. vs Fac.	1	1.87^{ns}	297.04*	60.75*	0.06^{ns}	0.42^{ns}	1,383.60^{ns}
Residue	16	25.89	11.06	12.13	57.00	4.00	31.32
Total	26						
CV (%)		4.55	14.43	7.64	8.60	0.98	5.12
L. Regression						62.14*	
Value p.						0.0012	
Q. Regression						8.98^{ns}	
p-value						0.1536	

DF: Degrees of Freedom. MS: mean square. * Significant at 5%. ns: not significant. CV (%): Coefficient of Variation. PS: Phenological stage. D x PS: Interaction between OMF dose and phenological stage. Ad. vs Fac.: Contrast between the additional treatment and the factorial. L. Regression: Linear regression. Q. Regression: Quadratic regression. p-value: Significance.

Table 4. Number of pods per plant (NPP) according to the organomineral fertilizer (OMF) doses and the application at different phenological stages.

Dose (kg ha^{-1})	Phenological stage	
	R_3	R_5
	nº plant^{-1}	
0.5	48.80 a	43.98 a
1.0	47.27 a	45.33 a
1.5	47.40 a	45.00 a
2.0	41.47 a	49.60 a

Means followed by the same letter do not differ at the 5% probability level by the Tukey test.

A divergent result was observed by Meyer et al. (2021), who, when conducting a study on the effect of the algae extract-based biostimulant Booster® on soybean crops, observed that there was a significant effect on the number of pods at doses of 0.68 and 0.75 L ha^{-1} in the application at V_4 and R_1, and for the number of pods on the branches, the best phenological stage of application was at R_1, with an increase of approximately 30%. According to these authors, this result probably occurred because, although rainfall was adequate during the experiment, high temperatures were recorded for relatively long periods during the reproductive phase, and the biostimulant may have mitigated the harmful effects of the heat.

For the 1000-grain mass, the linear regression analysis shows the results according to the OMF doses applied at the R_3 and R_5 phenological stages (Figure 2). At the R_3 stage, the highest values of 1000-grain mass were observed when the doses of 1.5 and 2 kg ha^{-1} were applied. However, at the R_5 stage, it was observed that the doses of 0.5 and 1 kg ha^{-1} provided the highest values of 1000-grain mass. According to Ramos et al. (2015), applications of biostimulants can be efficient when applied in low doses, acting on various metabolic processes in the plant, favoring the expression of the plant's genetic potential and promoting hormonal balance.

Concerning the interaction between doses and the phenological stage R_3, a similar result was observed by Moterle et al. (2008), who observed that the foliar application of the biostimulant Stimulate®, at its highest dose of 0.5 L ha^{-1}, provided a higher value of 1000-grain mass at the R_3 phenological stage compared to stage V_5, in the 2006/2007 crop season; the increase was of 7.65% and in the other doses evaluated the authors observed no difference for this variable.

Carvalho et al. (2013), when applying the biostimulant Stimulate® to the soybean cultivar BMX Don Mario 5.8.i RR (Apolo), at doses of 0.25, 0.50, 0.75, and 1,0 L ha^{-1}, at the V_5, R_1, and R_3 phenological stages, also observed a significant difference between the treatments, with the highest average for 1000-grain mas of 287.5 g, observed at a dose of 1 L ha^{-1} (highest dose), while the control treatment showed an average of 158 g. The interaction between the OMF doses and the application at different phenological stages can be explained by the fact that the R_3 phenological stage represents the start of pod formation, where there was a high demand for nutrients.

The soybean plant has a great capacity to absorb and use nutrients, conducting this process more successfully in its development phase, where the demands for nutrients are higher in the period between V_2 and R_5 (Barbosa et al., 2016). In addition, Gaspar et al. (2017), evaluating patterns of absorption, partitioning, and removal of dry matter and nitrogen through the assessment of various soybean genotypes and growing environments, indicated in their results that the accumulation of dry matter and nitrogen is minimal until R_1, but increases rapidly for periods of peak absorption close to R_3 and R_4, a result that corroborates the higher 1000-grain mass obtained in the present study with the highest OMF dose at this stage.

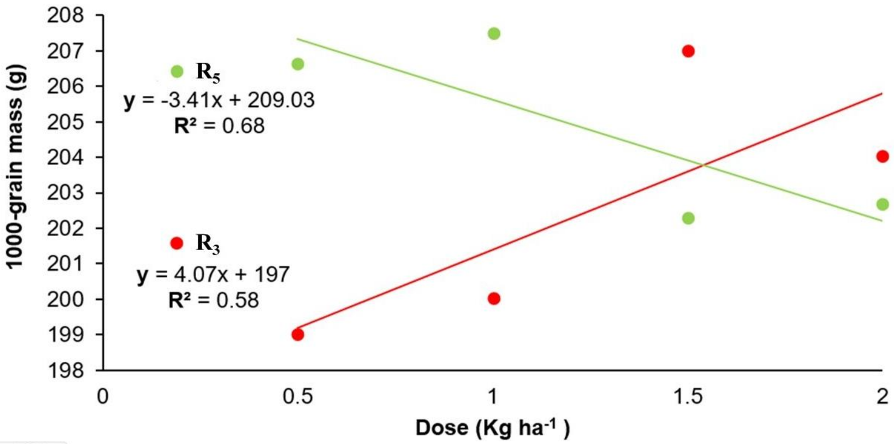

Figure 2. 1000-grain mass of soybean according to the mixed organomineral fertilizer (OMF) doses applied at different phenological stages.

Soybean development affects the rate at which nutrients are absorbed via the foliar route, with the absorption rate increasing from the flowering stage onwards, reaching its maximum at the R_5 stage, when it begins to decline. It is known that several factors can influence nutrient absorption, including the root system's ability to exploit the soil, soil and climate conditions, and water availability (Zobiole et al., 2012), which under field conditions may have influenced the plant's absorption capacity at the stages evaluated (R_3 and R_5).

A different result for 1000-grain mass was found by Kovalski et al. (2020) when they conducted a study on the effect of the biostimulant Biofran® at a dose of 250 ml ha^{-1}, Progibb® plus 2.4 D at doses of 200 ml ha^{-1} and 5 g ha^{-1}, respectively, and Internode®, at a dose of 1000 ml ha^{-1}, on different soybean cultivars: TGM 2185 IPRO, M 8372 IPRO, IMA 84114 RR, M 7110 IPRO, HO MARACAI IPRO, IMA 831 IPRO, NS 7667 IPRO.

In this research, a reduction in the 1000-grain mass was observed in the treatments mentioned in comparison to the control treatment in some cultivars, such as HO MARACAI, which showed a 1000-grain mass of 176.9 g for the control treatment and 170.5, 168.5, and 169.6 g for the other treatments, the IMA 831 IPRO cultivar showed 178.1 g for the control treatment and 167.5, 160.9, and 172.4 for the other treatments and, finally, the NS 7667 IPRO cultivar showed a 1000-grain mass of 208 g for the control treatment and lower values of 202.7, 181.4, and 206.5 for the treatments cited, respectively.

A divergent result was also found by Cavalcante et al. (2022), who, when conducting a study on the effect of a biostimulant based on algae extract (*Ascophyllum nodosum*), applied to the NS 7007 IPRO® soybean variety at doses of 0.5, 1, 1.5, and 2 L ha^{-1}, observed that the lowest doses, 0.5 and 1 L ha^{-1}, promoted the greatest increase in 1000-grain mass. The greatest increase, compared to the control treatment, of 5.03%, corresponding to 0.66 g, was seen at the lowest dose, however, this occurred with the application at the R_1 phenological stage, and the application at other stages was not assessed in this study.

Table 5 shows the results of the interaction between phenological stages and OMF doses for 1000-grain mass. It was observed that the averages for this variable were higher when the 0.5 and 1.0 doses were applied at phenological stage R_5; conversely, when the 1.5 kg ha^{-1} dose was applied at phenological stage R_3, there was a better result. For the dose of 2 kg ha^{-1}, there was no significant difference in the 1000-grain mass when comparing the two phenological stages.

Table 5. 1000-grain mass of soybean according to the organomineral fertilizer (OMF) doses and the application at different phenological stages.

Dose (kg ha^{-1})	Phenological stage	
	R_3	R_5
	--------------- g ---------------	
0.5	199.34 b	206.62 a
1.0	199.94 b	207.50 a
1.5	206.73 a	202.27 b
2.0	203.30 a	202.68 a

Means followed by the same letter do not differ at the 5% probability level by the Tukey test.

Some studies in the literature show that the results found for 1000-grain mass can vary according to the phenological stages of the soybean and the doses of biostimulants applied, such as that found by Moterle et al. (2008), in which a significant difference was observed between the phenological stages for 1000-grain mass when the dose of 0.5 ml ha^{-1} was applied via foliar application, with the highest average being observed at the R_3 stage compared to V_5. The authors, who also observed higher soybean yields with applications at R_3, explain that this result is probably because the stimulant applied at this stage serves as a drain for the release and/or remobilization of carbohydrates, giving rise to grains and positively influencing crop yields.

Another study conducted by Tartaro et al. (2021) evaluated the application of the plant regulator formulation 0.009% Kinetin, 0.005% Gibberellic Acid, and 0.005% 4-indol-3-yl butyric acid at a dose of 0.5 L ha^{-1}, at the V_2, V_5, R_1, and R_3 phenological stages of soybeans, and observed that the highest 1000-grain mass was observed when the biostimulant was applied at R_1 stage, without differing from the control, but there was a decrease of approximately 9% when the biostimulant was applied at R_3 stage, differing statistically from the application at R_1 stage. However, the authors of the study explain that water stress occurred at the R_3 stage, which may have affected the result obtained.

Table 6 shows the results of application at the R_3 and R_5 phenological stages on soybean yields. There was a significant difference between the phenological stages, with the highest average yield being observed when the application was made at the R_5 stage, with a 7.93% increase. A similar result was found by Silva et al. (2023) in a study aimed at verifying the effect of the Agri Gold® biostimulant in foliar application at different phenological stages in the soybean crop, in which the highest yields were observed in applications made at the R_5 stage and in application at the V_4+R_1 stages, with yields of 5659.8 and 5759.4 kg ha^{-1}, respectively, while the control (no application) achieved a yield of 4727.4 kg ha^{-1}.

A similar result was found by Silva et al. (2023) in a study aimed at verifying the effect of the Agri Gold® biostimulant in foliar application at different phenological stages in the soybean crop, in which the highest yields were observed in applications made at the R_5 stage and in application at the V_4+R_1 stages, with yields of 5659.8 and 5759.4 kg ha^{-1}, respectively, while the control (no application) achieved a yield of 4727.4 kg ha^{-1}.

Tartaro et al. (2021), on the other hand, found no significant difference in soybean yields with the application of a plant regulator formulated with 0.009% Kinetin, 0.005% Gibberellic Acid, and 0.005% 4-indol-3-yl butyric acid at different stages of crop development (V_2; V_5; R_1; R_3), although the application at stage R_1 provided an increase of 18% compared to the control treatment. In addition, the authors obtained superiority in applying the regulator evaluated for plant height when the application was made at the V_5 and R_1 stages and the number of grains per pod, with an application at all the phenological stages evaluated.

Similarly, Meyer et al. (2021), evaluating the effect of doses and stages of foliar application of a seaweed extract-based biostimulant on soybeans, found no difference between applications made at different phenological stages (V_4, R_1, and V_4+R_1) on crop yield. Although they did not observe any difference in soybean yields depending on the time of application, these authors obtained superiority in the number of flowers and pods with application at the R_1 stage.

The contrast between the additional treatment (control-no application) and the factorial was significant for the first pod insertion height and number of pods per plant (Table 7). Concerning the first pod insertion height, although there was a difference between the additional treatment (control) and the factorial, in both cases, the height did not represent a problem, according to Câmara (2022), to reduce the possibility of harvest losses, the first pod insertion height should be greater than 12 cm.

Concerning the number of pods per plant, the factorial showed a higher average for this variable than the additional treatment (control). This result can be explained by the fact that the application of OMF may have provided a greater quantity of minerals since it contains NPK, secondary macronutrients, and micronutrients, which were possibly used by the plants as reserve substances, thus inducing a reduction in plant abortion. Similarly, Meyer et al. (2021) observed a significant effect on the total number of soybean pods with the use of biostimulants, with treated plants showing 50 pods while untreated plants showed around 39 pods. Although there was a significant difference in grain yield due to the application of OMF at the two different phenological stages of the soybean, this was not the case when comparing the factorial with the control without application (Table 7).

Moterle et al. (2008), evaluating the effect of applying biostimulants to soybeans in two crop seasons, observed higher yields with the application of a dose of 211 ml ha^{-1} of bioregulator at the R_3 stage associated with seed treatment in the 2005/2006 crop season. However, in the second crop season, 2006/2007, there was no significant difference in grain yield between the treatments, although the results achieved were higher than those obtained in the first crop season.

For these authors, one of the basic principles for improving the efficacy of the bioregulator in soybean cultivation was adverse climatic conditions, i.e., the occurrence of a drought in the first crop season of the study. Bezerra et al. (2016) also point out that many researchers emphasize adverse climatic conditions as one of the basic principles for improving the effectiveness of bioregulators. Also, according to Schaich et al. (2022), one of the approaches to using biostimulants is to act on the primary and secondary physiological metabolisms of plants to minimize negative impacts in stressful situations.

Other studies have also demonstrated the effect of biostimulants in stressful situations, such as Cavalcante et al. (2020), who verified the efficiency of biostimulants in promoting a greater ability of soybean plants to withstand a period of water deficit. This study evaluated the physiological characteristics and grain yield of soybeans subjected to applying different biostimulants under the soil and climate conditions of the Cerrado region and found that biostimulants promoted a greater increase in soybean yields. The treatment with algae extract resulted in an average increase of 20.5% concerning the control treatment, while the treatment with fulvic acids increased grain yields by 22.05%. Furthermore, it was found that the biostimulants promoted an average increase of 46.66% in water potential.

Table 7. Contrast between the additional treatment (control treatment - no application) with the factorial.

Agronomic characteristics	Height	HGT. INS.	NPP	NGP	TGM	YIEL
Additional	112.53	0.14 b	41.53 b	87.66	204.01	3,436.06
Factor	111.69	0.24 a	46.87 a	87.82	203.61	3,458.83

Means followed by the same letter do not differ at the 5% probability level by the Tukey test.

Andrade et al. (2018) obtained a favorable response to the use of biostimulants in soybean crops under stress conditions; in this case, the authors evaluated the potential of using biostimulants to minimize the phytotoxic effects of glyphosate. In their study, they proved the beneficial effects of applying the biostimulants MC Extra and Megafol at the V_5 stage, MC Extra and Megafol at V_5 and R_5, respectively, MC Extra at V_5 and R_5, MC Extra and MC Cream at V_5 and R_5, respectively, and MC Cream at R_1. All these treatments had higher grain yields than those without biostimulants, which produced 4158 kg ha^{-1}, while the treatments above produced 4757, 4598, 4754, 4733, 4538, and 4723 kg ha^{-1}, respectively.

Oliveira et al. (2022) evaluated the agronomic characteristics of soybeans according to different levels of defoliation at different vegetative and reproductive stages and biostimulants applied via foliar. They found the beneficial effect of biostimulants, which significantly provided faster and more effective physiological recovery of the soybean crop when subjected to losses of leaf area at different levels of defoliation in both the vegetative and reproductive phases.

The results obtained in this study show that there is a need for more research into the efficacy of using mixed organomineral fertilizer (OMF) as a biostimulant in soybean cultivation, as well as more evaluations considering the application of different doses and at different phenological stages and in the face of stress situations. Although higher yields were not achieved with the use of the product, it is recommended that further research be conducted in similar and contrasting environments to the one observed in this study, as well as the application at other phenological stages.

4. Conclusions

As a biostimulant in soybean cultivation, the mixed organomineral fertilizer (OMF) increased the first pod insertion height and the number of pods per plant. Applying OMF did not lead to higher yields in the soybean crop compared to the control; however, when applied at the R_5 phenological stage, higher yields were observed compared to application at stage R_3.

The 1000-grain mass was influenced by the interaction between doses and applications at different phenological stages, with the highest doses increasing 1000-grain mass when applied at the R_3 stage and the lowest doses providing higher 1000-grain mass at the R_5 stage.

Authors' Contribution

Pedro Luid de Sousa Olivieira has carried out the field experiment, collected the data and writen the manuscript; Aracy Camilla Tardin Pinheiro Bezerra has writen, corrected and edited the final manuscript; Cássio do Prado Borges has conducted the statistical analysis and writen the original version; Carlos Gabriel Oliveira Mattos has collected the data and writen the original version; Deise Kelle Barbosa Ferreira has collected the data and writen the original version; Antônio Paulino da Costa Netto has elaborated and coordinated the planning, execution of the study, experimental design and writen and corrected the final version manuscript.

Acknowledgments

To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES for providing us with a master's and post-doctoral scholarship.

Bibliographic References

Andrade, C.L.L., Silva, A.G., Melo, G.B., Ferreira, R.V., Moura, I.C.S., Siqueira, G.G.C., 2018. Bioestimulantes derivados de *Ascophyllum nodosum* associados ao glyphosate nas características agronômicas da soja RR. Revista Brasileira de Herbicidas, 17(3), e592. DOI: https://doi.org/10.7824/rbh.v17i3.592.

Araújo, L.L.M., Ramos, D.T., Brachtvogel, A.R.K., 2021. Ação de bioestimulantes em cultivares comerciais de soja na região norte do vale Araguaia – MT. Revista PesquisAgro, 4(1), 1-19. DOI: https://doi.org/10.33912/pagro.v4i1.1146.

Barbosa, J.M., Rezende, C.F.A., Leandro, W.M., Ratke, R.F., Flores, R.A., Silva, A.R., 2016. Effects of micronutrients application on soybean yield. Australian Journal of Crop Science, 10(8), 1092–1097. DOI: https://doi.org/10.21475/ajcs.2016.10.08.p7367.

Bhering, L.L., 2017. Rbio: A Tool For Biometric And Statistical Analysis Using The R Platform. Crop Breeding and Applied Biotechnology, 17, 187-190. DOI: http://dx.doi.org/10.1590/198470332017v17n2s29.

Bezerra, A.R.G., Sediyama, T., Soares, M.M. 2016., Biorreguladores. In: Sediyama, T., (Ed.), Produtividade da Soja. Editora Mecenas, Londrina, p. 264-274.

BRASIL/MAPA. MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO. 2009. Regras para Análise de Sementes. Brasília, Ministério da Agricultura, Pecuária e Abastecimento, p. 346-347.

Câmara, G.M.S., 2022. Colheita, in: Silva, F., Borém, A., Sediyama, T., Câmara, G. (Ed.), Soja: do plantio à colheita. Oficina de Textos, São Paulo, p. 266-284.

Castro, P.R.C., Campos, G.R., Carvalho, M.E.A., 2019. Biorreguladores e bioestimulantes agrícolas. ESALQ, Piracicaba.

Cavalcante, W.S.S., Silva, N.F., Teixeira, M.B., Corrêa, F.R., Rodrigues, E., Cabral Filho, F.R., Martins, G.R., Cabral, P.H.F., Matias, V.C., Neto, J.G.M., Magalhães, Y.C.M., 2022. Potencial de utilização do extrato de algas marrom no estádio fenológico reprodutivo da soja. Research, Society and Development, 11(5), 1-10. DOI: http://dx.doi.org/10.33448/rsd-v11i5.28563.

Cavalcante, W.S.S., Silva, N.F., Teixeira, M.B., Cabral Filho, F.R., Nascimento, P.E.R., Corrêa, F.R., 2020. Eficiência dos bioestimulantes no manejo do déficit hídrico na cultura da soja. Irriga, 25(4), 754-763. DOI: https://doi.org/10.15809/irriga.2020v25n4p754-763.

Carvalho, J.C., ViecellI, C.A., Almeida, D.K., 2013. Produtividade e desenvolvimento da cultura da soja pelo uso de regulador vegetal. Acta Iguazu, 2(1), 1-11. DOI: https://doi.org/10.48075/actaiguaz.v2i1.8166.

Costa, C.E.M., Rezende, T.T., Silva, A.B., 2022. Balanço hormonal e produtividade de cafeeiro esqueletado com aplicação de bioestimulante. Research, Society and Development, 11(5), e12711527870. DOI: http://dx.doi.org/10.33448/rsd-v11i5.27870.

Francisco, E.A.B., Câmara, G.M.S., 2013. Desafios atuais para o aumento da produtividade da Soja. Informações Agronômicas, Piracicaba, 1(143), 11-16.

Ferrazza, F.L.F., Jacoboski, D.T.K., Wyrepkowski, A., Rodrigues, L., Figueiró, A.G., Paraginski, R.T., 2020. Qualidade de sementes e parâmetros produtivos de sementes de soja submetidas a diferentes tratamentos de sementes antes da semeadura. Research, Society and Development, 9(9), 1-17. DOI: http://dx.doi.org/10.33448/rsd-v9i9.6232.

Galindo, F.S., Teixeira Filho, M.C.M., Buzetti, S., Alves, C.J., Garcia, C.M.P., Nogueira, L.M., 2019. Extrato de algas como bioestimulante na nutrição e produtividade do trigo irrigado na região de Cerrado. Colloquium Agrariae, 15(1), 130-140. DOI: https://doi.org/10.5747/ca.2019.v15.n1.a277.

Gaspar, A.P., Laboski, C.A.M., Naeve, S.L., Conley, S.P., 2017. Dry matter and nitrogen uptake, partitioning, and removal across a wide range of soybean seed yield levels. Crop Science, 57(4), 2170–2182. DOI: https://doi.org/10.2135/cropsci2016.05.0322.

INMET. INSTITUTO NACIONAL DE METEOROLOGIA. Dados meteorológicos: banco de dados meteorológicos. https://portal.inmet.gov.br/ (acessado 03 de janeiro de 2023).

Kocira, S., 2019. Effect of amino acid biostimulant on the yield and nutraceutical potential of soybean. Chilean Journal of Agricultural Research, 79(1), 17-25. DOI: http://dx.doi.org/10.4067/S0718-58392019000100017.

Kovalski, A.R., Castro, Y.O., Ramos, D.T., Araújo, L.L.M, 2020. Avaliação do desempenho agronômico de diferentes cultivares de soja (*Glycine max* (L.) Merrill) com uso de bioestimulante e herbicida hormonal. Revista PesquisAgro, 3(1), 1-20. DOI: https://doi.org/10.33912/pagro.v3i1.651.

Mariano, Z.F., Rocha, J.R.R., 2016. Temperaturas máximas e mínimas absolutas em cidades de pequeno porte: exemplo de Jataí-GO. Revista de Geografia, 33(4), 214-219.

Meyer, R.F., Júnior, V.O., Bernardes, J.V.S., Coelho, V.P.M., 2021. Foliar spraying of a seaweed-based biostimulant in soybean. Revista Caatinga, 34(1), 1-9. DOI: https://doi.org/10.1590/1983-21252021v34n111rc.

Moterle, L.M., Santos, R.F., Braccini, A.L., Scapim, C. A., Barbosa, M.C., 2008. Efeito da aplicação de biorregulador no desempenho agronômico e produtividade da soja. Acta Scientiarum. Agronomy, 30(5), 701-709. DOI: https://doi.org/10.4025/actasciagron.v30i5.5971.

Neumaier, N., Farias, J.R.B., Nepomuceno, A.L., Mertz-Henning, L.M., Foloni, J.S.S., Moraes, L.A.C., Goncalves, S.L., 2020. Ecofisiologia da soja. In: Seixas, C.D.S., Neumaier, N., Balbinot Junior, A.A., Krzyzanowski, F.C., Leite, R.M.V.B. de C. (Ed.), Tecnologias de produção de soja. Embrapa Soja, Londrina, p. 33-54.

Oliveira, A.P.D., Ferreira, B.S., 2020. Biotecnologia aliada da agricultura e na produtividade da soja. Revista Científica Eletrônica de Ciências Aplicadas da FAIT, 1(2), 1-13.

Oliveira, G.S., Duarte Júnior, J.B., Cieslak, L., Costa, A.C.T., Kuhn, O.J., 2022. Caracteres agronômicos da soja em função da aplicação de bioestimulantes em diferentes épocas e níveis de desfolha. Brazilian Journal of Development, 8(9), 61396-61415. DOI: https://doi.org/10.34117/bjdv8n9-068.

Ramos, A.R., Binotti, F.F.S., Silva, T.R., Silva, U.R., 2015. Bioestimulante no condicionamento fisiológico e tratamento de sementes de feijão. Revista Biociências, 21(1), 76-88.

Schaich, G., Tagliapietra, E.L., Winck, J.E.M., Silva, M.R., Alves, A.F., Munareto, G.G., Poersh, A.H., Ribeiro, B.S.M.R., Quintero, C.E., Richter, G.L., Balest, D.S., Inklman, V.B., Schneider, R.A., Bexaira, K.P., Savegnago, C., Paula, L.S., Nora, M.D., Arevalo, E.S., Báez, M.S.A., Pes, L.Z., Streck, N.A., Zanon, A.J., 2022. Bioestimulantes. in: Tagliapietra, E.L., Winck, J.E.M., Silva, M.R., Alves, A.F., Munareto, G.G., Poersh, A.H., Ribeiro, B.S.M.R., Quintero, C.E., Richter, G.L., Balest, D.S., Inklman, V.B., Schneider, R.A., Bexaira, K.P., Savegnago, C., Nora, M.D., Paula, L.S., Arevalo, E.S., Báez, M.S.A., Pes, L.Z., Streck, N.A., Zanon, A.J., (Eds.), Ecofisiologia da Soja Visando Altas Produtividades. S.N., Santa Maria, p. 293-308.

Santos, H.D., Jacomine, P., Anjos, L., Oliveira, V., Lumbreras, J., Coelho, M., Almeida, J., Cunha, T., Oliveira, J., 2018. Embrapa: Sistema brasileiro de classificação de solos, 5 ed. Embrapa Editora, Brasília-DF.

Silva, N.F., Clemente, G.S., Texeira, M.B., Soares, F.A.L., Cunha, F.N., Azevedo, L.O.S., Souza, F.C., Santos, M.A., 2017. Uso de fertilizantes foliares na promoção do manejo fisiológico específico na fase reprodutiva da cultura da soja. Global Science and Technology, 10(3), 1-15.

Silva, A.V., Andrade, C.L.L., Cabral Filho, F.R., Teixeira, M.B., Ferreira, T.M., Ventura, M.V.A., 2023. Effects of Agri Gold® (*Ascophyllum nodosum*) biostimulant on growth and development of soybean. Brazilian Journal of Science, 2(1), 72–81. DOI: https://doi.org/10.14295/bjs.v2i1.242.

Yakhin, O.I., Lubyanov, A.A., Yakhin, I.A., Brown, P.H., 2017. Biostimulants in Plant Science: A Global Perspective Frontiers in Plant Science, 7(49), 1-32. DOI: https://doi.org/10.3389/fpls.2016.02049.

Tartaro, E.L., Silva, I. F., Prates, P.A.M., Silva, S.F., Hirsch, O., Tosetto, B., Viecelli, C.A., 2021. Influência da aplicação de regulador vegetal em diferentes estágios fenológicos da soja. Revista Agropampa, 1(1), 1-8.

Torsian, W.S., Kikuti, A.L.P., Kikuti, H., Pereira, C.E., 2021. Bioestimulantes no desenvolvimento da cana-de-açúcar. Magistra, 31, 625–634.

Zobiole, L.H.S., Oliveira Jr., R.S., Constantin, J., Oliveira, J.R.A., Castro, C., Oliveira, F.A., Kremer, R.J., Moreira, A., Romagnoli, L.M., 2012. Acúmulo de nutrientes em soja convencional e soja RR em diferentes tipos de controle de planta daninha. Planta Daninha, 30(1), 75-85. DOI: https://doi.org/10.1590/S0100-83582012000100009.