

Sustainable use of *Ascophyllum nodosum* extract to enhance maize (*Zea mays L.*) productivity under water stress

Uso sustentável do extrato de *Ascophyllum nodosum* para aumentar a produtividade do milho (*Zea mays L.*) sob estresse hídrico

Uso sostenible del extracto de *Ascophyllum nodosum* para mejorar la productividad del maíz (*Zea mays L.*) bajo estrés hídrico

Received: 05/09/2026 | Accepted: 05/12/2026 | Published: 05/18/2026

Marcos Gimenes Martins Filho

ORCID: <https://orcid.org/0009-0004-5073-5635>

Universidade Cesumar, Brazil

E-mail: marcosgimenes2002@hotmail.com

Aline Lopes

ORCID: <https://orcid.org/0000-0001-5771-4643>

Universidade Cesumar, Brazil

E-mail: aline.llopes@unesumar.edu.br

Yris Ayumi Toyotani Camacho

ORCID: <https://orcid.org/0009-0004-3137-5574>

Universidade Cesumar, Brazil

E-mail: yrisatc@gmail.com

Stephanie Abisag Sáez Meyer Piazza

ORCID: <https://orcid.org/0000-0001-8301-6734>

Universidade Cesumar, Brazil

E-mail: s.meyer.piazza@gmail.com

Francieli Gasparotto

ORCID: <https://orcid.org/0000-0002-4038-7364>

Universidade Cesumar, Brazil

E-mail: francielli.gasparotto@unesumar.edu.br

Anny Rosi Mannigel

ORCID: <https://orcid.org/0000-0003-3371-802X>

Universidade Cesumar, Brazil

E-mail: anny.mannigel@unesumar.edu.br

Edneia Aparecida de Souza Paccola

ORCID: <https://orcid.org/0000-0002-3182-3224>

Universidade Cesumar, Brazil

E-mail: edneia.paccola@unesumar.edu.br

Abstract

In the pursuit of improved agricultural productivity and resilience, the adoption of biostimulants has increased significantly in modern farming systems. Among these, products based on *Ascophyllum nodosum* extract have gained prominence due to their potential to enhance plant tolerance to abiotic stresses. This study aimed to evaluate the effects of different doses of a seaweed-extract-based biostimulant applied via foliar spraying under water stress conditions on maize (*Zea mays L.*) productivity. The experiment was conducted from February to July 2025 in a rural area of São Carlos do Ivaí, Paraná, Brazil, using the hybrid Pioneer 3310. A randomized complete block design was adopted, with five treatments (0, 150, 300, 600, and 1200 mL per alqueire) and four replications, totaling 20 experimental units. Applications were performed at the V4 and pre-tasseling stages. The evaluated variables included ear weight, number of rows per ear, number of kernels per row, and economic return. The results demonstrated that the application of the biostimulant significantly increased maize productivity, with the 600 mL dose showing the highest yield and best economic performance. Higher doses did not result in additional gains, suggesting a saturation effect. Therefore, the use of *Ascophyllum nodosum* extract represents a viable and sustainable strategy to enhance maize productivity under water stress conditions.

Keywords: Biostimulant; Water stress; Maize yield; *Ascophyllum nodosum*; Sustainable agriculture.

Resumo

Em busca de maior produtividade e segurança agrícola, o uso de bioestimulantes tem se destacado nos sistemas produtivos modernos. Entre eles, produtos à base de extrato da alga *Ascophyllum nodosum* vêm ganhando relevância

devido ao seu potencial em aumentar a tolerância das plantas a estresses abióticos. O presente estudo teve como objetivo avaliar os efeitos de diferentes doses de um bioestimulante à base de extrato de alga, aplicado via foliar sob condições de estresse hídrico, na produtividade do milho (*Zea mays L.*). O experimento foi conduzido entre fevereiro e julho de 2025, em área rural de São Carlos do Ivaí – PR, utilizando o híbrido Pioneer 3310. O delineamento experimental foi em blocos casualizados, com cinco tratamentos (0, 150, 300, 600 e 1200 mL por alqueire) e quatro repetições, totalizando 20 unidades experimentais. As aplicações ocorreram nos estádios V4 e pré-panoamento. Foram avaliados peso de espiga, número de fileiras, número de grãos por fileira e retorno econômico. Os resultados indicaram que a aplicação do bioestimulante aumentou significativamente a produtividade do milho, com destaque para a dose de 600 mL, que apresentou maior rendimento e melhor desempenho econômico. Doses superiores não proporcionaram ganhos adicionais, indicando possível saturação da resposta. Assim, o uso do extrato de *Ascophyllum nodosum* mostra-se uma alternativa viável e sustentável para incremento da produtividade do milho sob estresse hídrico.

Palavras-chave: Bioestimulante; Estresse hídrico; Produtividade; *Ascophyllum nodosum*; Agricultura sustentável.

Resumen

En la búsqueda de una mayor productividad y sostenibilidad agrícola, el uso de bioestimulantes ha cobrado relevancia en los sistemas de producción. Entre ellos, los productos a base de extracto del alga *Ascophyllum nodosum* destacan por su capacidad de aumentar la tolerancia de las plantas al estrés abiótico. Este estudio tuvo como objetivo evaluar los efectos de diferentes dosis de un bioestimulante a base de extracto de algas, aplicado vía foliar bajo condiciones de estrés hídrico, sobre la productividad del maíz (*Zea mays L.*). El experimento se llevó a cabo entre febrero y julio de 2025 en una zona rural de São Carlos do Ivaí, Paraná, Brasil, utilizando el híbrido Pioneer 3310. Se adoptó un diseño de bloques completamente al azar con cinco tratamientos (0, 150, 300, 600 y 1200 mL por alqueire) y cuatro repeticiones, totalizando 20 unidades experimentales. Las aplicaciones se realizaron en las etapas V4 y pre-emisión de la panoja. Se evaluaron peso de espiga, número de hileras, número de granos por hilera y análisis económico. Los resultados mostraron que la aplicación del bioestimulante incrementó significativamente la productividad del maíz, destacándose la dosis de 600 mL con el mayor rendimiento y mejor desempeño económico. Dosis superiores no generaron beneficios adicionales, lo que sugiere un efecto de saturación. Por lo tanto, el uso de extracto de *Ascophyllum nodosum* es una alternativa viable y sostenible para mejorar la productividad del maíz bajo estrés hídrico.

Palabras clave: Bioestimulante; Estrés hídrico; Productividad; *Ascophyllum nodosum*; Agricultura sostenible.

1. Introduction

Maize (*Zea mays L.*) is one of the most widely cultivated crops worldwide and plays a fundamental role in global food security. Its origin remains debated among researchers, with evidence suggesting domestication in Mexico (Matsuoka et al., 2002). Brazil stands out as one of the world's leading producers and exporters of maize, with national production projected to reach approximately 139 million tons in 2025, according to the Ministry of Agriculture, Livestock and Supply (MAPA, 2025).

Maize production in Brazil is divided into two main growing seasons. The first season occurs between October and November, with harvest from March to April, while the second season, commonly known as “safrinha”, is planted between February and March and harvested from June to July, depending on the region. This second crop accounts for approximately 77.2% of total national production (Guimarães, 2024).

The state of Paraná has gained prominence in maize production, contributing significantly to national exports. Between January and July 2021, the state exported 405 thousand tons of maize, representing a 13% increase compared to the previous year, and reaching approximately 14.6 million tons in 2023 (GOV, 2024). However, adverse climatic conditions have negatively impacted productivity. In 2024, for example, reduced rainfall and high temperatures led to losses of nearly 20% in maize production in the state (Toledo, 2024).

Water stress is considered one of the main limiting factors in maize cultivation and may result in yield losses of up to 100%, depending on the crop developmental stage. The total water requirement for maize throughout its cycle ranges from 400 to 700 mm, distributed as follows: 3.5 to 5.0 mm day⁻¹ from emergence to V6, 5.0 to 6.0 mm day⁻¹ from V7 to VT, 7.0 to 8.0 mm day⁻¹ from R1 to R5, and 5.0 to 6.0 mm day⁻¹ from R5 to physiological maturity (Zottis, 2023).

Water deficit occurring during the tasseling stage may prevent ear formation, while stress during pollination results in

poorly formed ears and reduced yield (Silva et al., 2021). Similarly, Almeida (2016) reported that maize exhibits high sensitivity to water deficit during the tasseling stage, leading to reduced leaf water potential, impaired plant development, and significant productivity losses. In addition, water stress negatively affects root and shoot development, reduces leaf area, and accelerates leaf senescence, ultimately compromising plant growth and yield (Galbiatti et al., 2004; Zottis, 2023).

In this context, the use of biostimulants has emerged as a promising strategy to mitigate the effects of abiotic stress and enhance crop productivity. Among these, seaweed-based biostimulants, particularly those derived from *Ascophyllum nodosum*, have gained increasing attention due to their ability to improve plant tolerance to water stress (El Boukhari et al., 2020). The application of seaweed extracts can stimulate enzymatic activity, such as nitrate reductase, enhancing nitrogen uptake and contributing to plant defense mechanisms under stress conditions (El Boukhari et al., 2020). These extracts are also rich in plant growth regulators, including auxins, cytokinins, and gibberellins (Carvalho et al., 2014).

Furthermore, seaweed extracts act as natural chelating agents, improving nutrient absorption and soil structure, which promotes root development and enhances plant resilience to both biotic and abiotic stresses (Mukherjee & Patel, 2019). The species *Ascophyllum nodosum* is particularly rich in bioactive compounds such as polysaccharides and amino acids, which play important roles in plant metabolism and stress tolerance (Silva; Cunha; Silva, 2022; Alcântara, 2019).

Commercial products based on this seaweed have also demonstrated positive effects on plant physiology. For example, ExpertGrow® (Adama, 2023) influences secondary metabolism, including protein expression, photosynthesis, growth, and stress resistance. Similarly, Acadian (Koppert, 2022) has been reported to enhance nutrient uptake, stimulate root growth, increase plant vigor, and improve final yield by allowing plants to express their full genetic potential.

Given the increasing frequency of water stress events and the need for sustainable agricultural practices, evaluating the effectiveness of seaweed-based biostimulants becomes essential for improving maize productivity under limiting environmental conditions. Therefore, this study aimed to evaluate the efficiency of different doses of *Ascophyllum nodosum* extract on maize productivity by assessing ear weight, number of kernels per row, number of rows per ear, and economic viability; we hypothesized that the application of this seaweed-based biostimulant would significantly enhance crop performance under water stress conditions, with intermediate doses providing the greatest agronomic and economic benefits due to a potential saturation effect at higher concentrations

2. Methodology

An experimental, field study was conducted (Risemberg et al., 2026), using a qualitative and quantitative approach (Pereira et al., 2018) and employing statistics and statistical criteria (Shitsuka et al., 2014; Costa Neto & Bekman, 2009).

The study was conducted in a rural area of São Carlos do Ivaí, Paraná State, Brazil, located in the northwestern region of the state (23°18'06" S, 52°28'41" W), at an altitude of approximately 300 m. The regional climate is classified as humid subtropical mesothermal, with an average annual temperature of approximately 22.0°C and annual precipitation ranging from 1,200 to 1,600 mm.

The experiment was carried out in an area of approximately 2 alqueires (48,400 m²), provided by a local farmer (Figure 1). The maize crop was cultivated from February to July 2025, within the recommended sowing period for the species. The hybrid Pioneer 3310 was used, with an approximate growth cycle of 140 days. Row spacing was 0.45 m, and each experimental plot had a total area of 16.2 m².

Figure 1 - Aerial view of the experimental field in São Carlos do Ivaí, Paraná, Brazil.



Source: Google Maps.

Soil samples were collected from multiple points across the experimental area to ensure representativeness, using a soil auger at a depth of 0–20 cm, following EMBRAPA recommendations (Embrapa, 2017).

The samples were sent to the AgriSolum Institute (Maringá, PR) for chemical and physical analyses, which were used to guide fertilization management. According to the results, the soil presented a clayey texture, composed of 40% clay, 3% silt, and 57% sand, classified as Type 3.

Based on the Brazilian Soil Classification System (Embrapa, 2021), the soil was identified as a dystrophic Red Latosol, characterized by its intense reddish color due to the presence of iron oxides (Fe_2O_3). Chemically, the soil showed low fertility, with low levels of calcium and magnesium, as well as low base saturation (V%) (Table 1).

Table 1 - Chemical analysis of the soil in the experimental area.

Ca^{2+}	Mg^{2+}	K^+	Al^{3+}	H + Al	S.B.	CTC	M.O.	V	P	pH CaCl_2
(cmolc dm^{-3})	(cmolc dm^{-3})	(cmolc dm^{-3})	(cmolc dm^{-3})	(cmolc dm^{-3})	(cmolc dm^{-3})	(cmolc dm^{-3})	(%)	(%)	(mg dm^{-3})	–
1.61	0.54	0.15	0.24	3.80	2.30	2.54	1.76	37.70	13.32	4.30

Source: AgriSolum Institute (2025).

Base fertilization was performed using NPK (10-15-15) at a rate of 700 kg per alqueire, uniformly applied across all treatments. The crop was grown under rainfed conditions, simulating conventional field practices. All plots received the same agronomic management, including pest control (leafhopper and aphids) and preventive fungicide applications.

Border rows were excluded from evaluations to minimize edge effects. The experimental design was a randomized complete block design (RCBD), consisting of five treatments and four replications, totaling 20 experimental units (Figure 2).

Figure 2 - Layout of the randomized complete block design with five treatments and four replications.



Source: Authors (2025).

The treatments consisted of different doses of a seaweed-extract-based biostimulant (*Ascophyllum nodosum*), as follows:

- **T1:** Control (no application)
- **T2:** 150 mL per alqueire
- **T3:** 300 mL per alqueire
- **T4:** 600 mL per alqueire
- **T5:** 1200 mL per alqueire

All treatments were applied at two growth stages: V4 (four fully expanded leaves with visible ligules) and pre-tasseling (onset of tassel emergence). Applications were performed using a backpack electric sprayer equipped with a four-nozzle boom (MIKOTO®), with a flow rate of 6 L min⁻¹.

The following variables were evaluated: thousand-grain weight, number of kernels per row, number of rows per ear, ear weight, and grain yield.

Maize yield was estimated based on the grain weight obtained from sampled plants and extrapolated to hectares according to the following equation:

$$\text{Yield (bags ha}^{-1}\text{)} = \frac{\left(\frac{P_g}{N_p}\right) \times D}{60}$$

where:

- P_g = total grain weight obtained from the sample (kg);
- N_p = number of sampled plants;
- D = plant population density (plants ha⁻¹);
- 60 = standard weight of one maize bag (kg).

The experimental data were subjected to analysis of variance (ANOVA) using a randomized complete block design. When significant differences among treatments were detected, means were compared using Tukey's test at the 5% probability

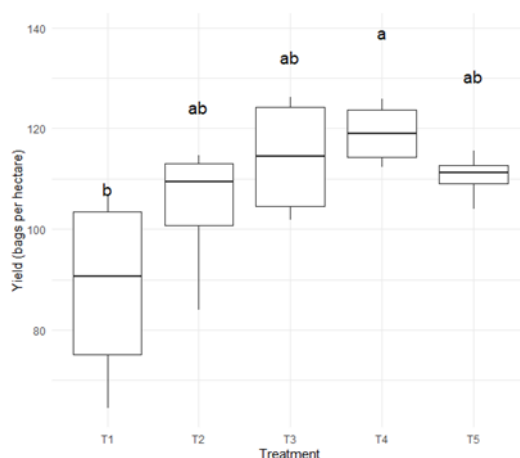
level. The assumptions of normality and homogeneity of variances were verified using the Shapiro–Wilk and Levene tests, respectively. Additionally, regression analysis was performed to evaluate the dose-response relationship of *Ascophyllum nodosum* extract on maize yield. All statistical analyses and graphical procedures were performed using the R 4.3.3 software environment.

3. Results and Discussion

The assumptions required for the analysis of variance were satisfied. The Shapiro–Wilk test confirmed the normal distribution of residuals ($W = 0.9707$; $p = 0.7695$), while Levene’s test indicated acceptable homogeneity of variances among treatments ($p = 0.055$). These results demonstrate the adequacy and reliability of the experimental design and statistical procedures adopted.

The analysis of variance (ANOVA) revealed a marginal effect of *Ascophyllum nodosum* extract doses on maize yield ($F = 3.082$; $p = 0.058$), indicating a response trend close to the conventional significance threshold. In contrast, the block effect was not significant ($p = 0.788$), confirming the homogeneity of the experimental area and reducing the likelihood of spatial interference among plots (Figure 3).

Figure 3 - Maize yield (bags ha^{-1}) under different doses of *Ascophyllum nodosum* extract applied during the V4 and pre-tasseling stages. Bars followed by the same letter do not differ significantly according to Tukey’s test at the 5% probability level.

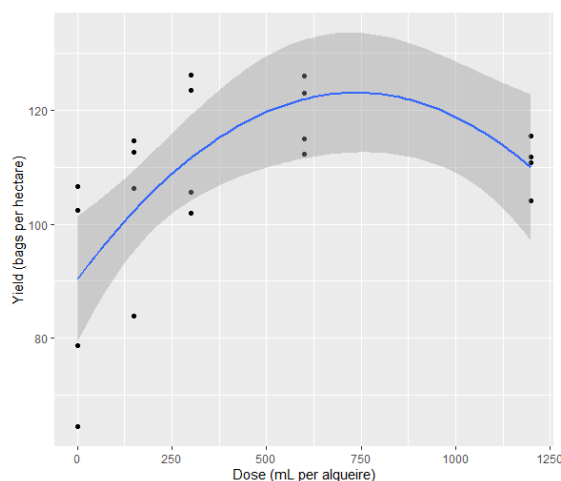


Source: Authors (2026).

Although treatment effects were only marginally significant in ANOVA, a clear biological response pattern was observed. Grain yield increased progressively with increasing doses up to intermediate levels, followed by a slight decline at the highest dose tested. This behavior was further confirmed by the quadratic regression analysis, which demonstrated a significant dose-response relationship ($F = 7.368$; $p = 0.0049$). Both the linear and quadratic terms were significant ($p = 0.0021$ and $p = 0.0057$, respectively), indicating that maize productivity responded nonlinearly to increasing doses of seaweed extract.

The regression model explained approximately 40% of the variation in grain yield (adjusted $R^2 = 0.4013$), suggesting that the biostimulant dose was an important factor influencing crop performance under field conditions. The estimated optimal dose obtained from the quadratic model was approximately 735 mL al^{-1} , very close to the experimentally observed best treatment (600 mL al^{-1}), reinforcing the existence of a biological optimum for the use of *Ascophyllum nodosum* extract in maize cultivation (Figure 4).

Figure 4 - Quadratic dose-response curve for maize yield (bags ha⁻¹) as a function of *Ascophyllum nodosum* extract doses applied under field conditions. The estimated optimal dose was approximately 735 mL per alqueire, indicating maximum technical efficiency for grain yield.



Source: Authors (2026).

Table 2 shows the effects of the treatments on ear weight, grain yield, number of rows per ear, and number of kernels per row. Significant increases in ear weight and grain yield were observed with the application of the biostimulant, particularly at intermediate doses. The treatment with 600 mL al⁻¹ resulted in the highest ear weight (0.1339 kg) and grain yield (119.06 bags ha⁻¹), differing statistically from the control treatment. In contrast, the number of rows per ear did not differ significantly among treatments, suggesting that this trait was less responsive to the biostimulant application.

Table 2 - Mean values of ear weight (EW), yield (Y), number of rows per ear (NRE), and number of kernels per row (NKR).

Treatment	EW (kg)	Y (bags ha ⁻¹)	NRE	NKR
0 mL	0.0991 B	88.06 B	13.50 A	28.26 B
150 mL	0.1174 AB	104.36 AB	13.83 A	31.81 A
300 mL	0.1286 AB	114.29 AB	13.60 A	31.99 A
600 mL	0.1339 A	119.06 A	13.66 A	32.74 A
1200 mL	0.1243 AB	110.52 AB	14.08 A	32.69 A
C.V.	12.75%	12.75%	3.98%	4.87%

Means followed by the same letter within a column do not differ significantly according to Tukey's test at the 5% probability level. Source: Authors (2026).

The number of kernels per row increased substantially with seaweed extract application, especially at doses between 150 and 600 mL al⁻¹. These findings indicate that the increase in productivity was primarily associated with improvements in kernel set and grain filling rather than changes in ear architecture. According to Santos et al. (2013), some reproductive traits in maize may exhibit limited responsiveness to biostimulant applications, depending on environmental and physiological conditions.

The superior performance observed at intermediate doses may be associated with the bioactive compounds present in *Ascophyllum nodosum* extract, including amino acids, polysaccharides, micronutrients, cytokinins, auxins, and gibberellins. These compounds act directly on plant metabolism, stimulating enzymatic activity, nutrient absorption, photosynthetic efficiency, and root development (Alcântara, 2019). Enhanced root growth may have improved water and nutrient uptake, contributing to greater tolerance to transient drought conditions during critical growth stages.

The reduction in productivity observed at the highest dose (1200 mL al⁻¹) suggests a possible saturation effect or metabolic imbalance caused by excessive concentrations of bioactive compounds. Similar nonlinear responses have been reported in studies involving biostimulants, in which moderate doses promote physiological stimulation, whereas excessive doses may disrupt hormonal balance and reduce metabolic efficiency (Cruz et al., 2024).

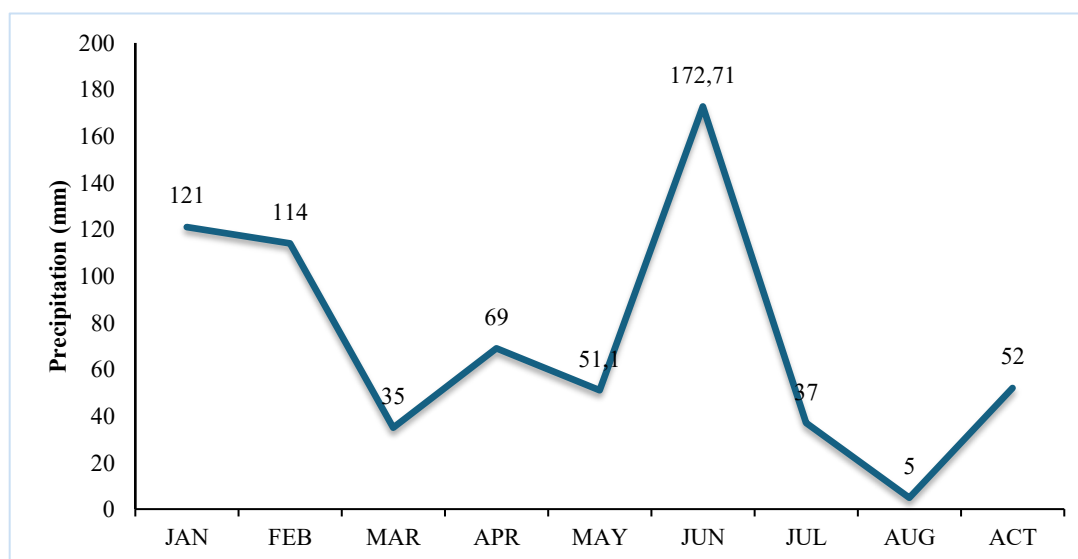
Environmental conditions during the experiment likely played an important role in the magnitude of the observed responses. Rainfall distribution throughout the crop cycle was irregular, with lower precipitation occurring during March, coinciding with vegetative growth stages characterized by high water demand (Figure 5).

The reduction in rainfall during this period may have imposed moderate water stress on the plants, particularly during the V4 stage, when rapid vegetative growth and root system expansion occur. Under such conditions, water limitation can directly affect nutrient uptake, leaf expansion, and biomass accumulation, ultimately impacting grain yield, as highlighted by Albuquerque (2010).

In the subsequent months, especially April and May, precipitation levels were more favorable, providing intermediate soil moisture conditions. However, the transient water deficit observed earlier in the cycle may have influenced plant development during critical stages. In this context, the application of *Ascophyllum nodosum* extract likely contributed to mitigating the effects of water stress, enhancing plant resilience through physiological mechanisms such as improved osmotic adjustment, stimulation of root growth, and increased efficiency in nutrient absorption (Alcântara, 2019; Cruz et al., 2024).

This interpretation is consistent with studies demonstrating that the effectiveness of biostimulants is often more pronounced under abiotic stress conditions, particularly water limitation (Martins et al., 2016; Ferreira et al., 2016). The improved performance observed at intermediate doses suggests that the biostimulant enhanced the plant's ability to cope with temporary water stress, maintaining metabolic activity and supporting grain filling even under suboptimal environmental conditions.

Figure 5 - Monthly precipitation (mm) in São Carlos do Ivaí, PR, Brazil, with indication of treatment application periods.



Source: Authors (2026).

The response observed in the present study was likely intensified by the chemical characteristics of the soil, which exhibited high acidity (pH 4.3), low nutrient availability, and low base saturation (V% = 37.7). Under restrictive soil conditions, the beneficial effects of biostimulants tend to become more evident because plants are subjected to greater

physiological stress. Martins et al. (2016) reported limited responses to biostimulants in maize cultivated under optimal fertility conditions, suggesting that environmental stress is an important factor modulating the effectiveness of these products. Similarly, Ferreira et al. (2016) observed no significant effects of seaweed-based biostimulants under favorable environmental conditions, reinforcing the hypothesis that their benefits are more pronounced under abiotic stress scenarios.

The present findings agree with studies reporting positive effects of *Ascophyllum nodosum* extract on grain crops. Silva (2018) observed increases in maize growth and productivity following applications at the V4 and V8 stages, attributing these effects to improved root development and greater plant vigor. Likewise, Prada Neto et al. (2010) reported higher maize yields following seed treatment with biostimulants containing seaweed extract, especially under water-limited conditions. Similar responses have also been described for soybean crops, where foliar applications of *Ascophyllum nodosum* promoted gains in thousand-grain weight and final productivity (Wurlitzer and Simonetti, 2024).

3.1 Economic Analysis

The economic analysis corroborated the agronomic results, demonstrating that the treatment with 600 mL al⁻¹ provided the highest economic return (Table 3). This treatment generated a net profit of R\$ 14,219.00 per alqueire, representing an increase of approximately 33.5% compared to the control treatment.

Although the regression model estimated a theoretical optimum near 735 mL al⁻¹, the 600 mL al⁻¹ treatment represented the best balance between productivity gains and product cost under practical field conditions. Higher doses resulted in reduced profitability due to increased input costs combined with lower productive efficiency, reinforcing the occurrence of diminishing returns at elevated concentrations.

These results demonstrate that the use of *Ascophyllum nodosum* extract can be economically advantageous when applied at appropriate doses, particularly under environments subjected to moderate abiotic stress. Therefore, intermediate doses represent the most technically and economically viable strategy for sustainable maize production in the northwest region of Paraná.

Table 3 - Economic analysis of treatments with different doses of seaweed extract in maize.

Treatment	Dose (mL al ⁻¹)	Yield (bags al ⁻¹)	Revenue (R\$)	Product cost per alqueire (R\$)	Profit (R\$)
T1	0	213.0	10,651.00	0.00	10,651.00
T2	150	252.5	12,632.00	43.50	12,588.50
T3	300	276.2	13,824.00	87.00	13,737.00
T4	600	288.1	14,393.00	174.00	14,219.00
T5	1200	267.4	13,365.00	348.00	13,017.00

Source: Authors (2026).

4. Conclusion

The application of *Ascophyllum nodosum* extract promoted positive effects on maize productivity, particularly at intermediate doses. Regression analysis confirmed a significant quadratic dose-response relationship, with the estimated optimal dose being approximately 735 mL al⁻¹.

Among the evaluated treatments, the dose of 600 mL al⁻¹ showed the best agronomic and economic performance, resulting in higher grain yield and profitability. Doses above this level did not provide additional gains, suggesting a saturation effect in plant response to the biostimulant.

Overall, the results indicate that *Ascophyllum nodosum* extract represents a promising and sustainable alternative for

improving maize productivity under moderate water stress conditions, especially in low-fertility soils typical of the northwest region of Paraná.

Acknowledgments

To Fundação Araucária / Seti-PR / Senar-PR, and the Cesumar Institute of Science, Technology, and Innovation – ICETI/UNICESUMAR for granting a scholarship and financial support for conducting the research. A.L. also acknowledges Fundação Araucária for the Research Productivity Fellowship.

References

- ADAMA. (2023). *ExpertGrow*. ADAMA. <https://www.adama.com/brasil/pt/protecaode-cultivos/biossolucoes-e-adjuvante/expertgrow>.
- Albuquerque, P. E. P. (2010) Manejo de Irrigação: Cultivo do Milho. In: EMBRAPA MILHO E SORGO. Sistema de Produção, 1 – Cultivo do Milho. 6. ed. eletrônica. Sete Lagoas: Embrapa Milho e Sorgo. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/81707/1/Manejo-irrigacao.pdf>.
- Alcântara, H. P., & Porto, F. G. M. (2019). *Uso de extrato de algas e aminoácidos na agricultura brasileira* (Circular Técnica, 17). ISAH.
- Almeida, B. M. de. (2016). *Déficit e excesso hídrico na cultura do milho (Zea mays L.) em ambiente protegido* [Tese de doutorado, Universidade de São Paulo].
- Carvalho, M. E. A., & Castro, P. R. C. (2014). *Extratos de algas e suas aplicações na agricultura*. Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo. ESALQ-USP
- Costa Neto, P. L. O. & Bekman, O. R. (2009). *Análise estatística da decisão*. Editora Blucher..
- Cruz, J. A. D. (2024). *Aplicação de aminoácido e extrato de alga em milho* [Dissertação de mestrado, Instituto Federal de Educação, Ciência e Tecnologia Baiano]. Repositório IF Baiano
- El Boukhari, M. E. M., et al. (2020). Trends in seaweed extract based biostimulants. *Plants*, 9(3), 359. <https://doi.org/10.3390/plants9030359>
- EMBRAPA. (2017). *Análise de solo: Procedimentos para coleta de amostras*. EMBRAPA Solos.
- EMBRAPA. (2021). Latossolos vermelhos. EMBRAPA Solos.
- Ferreira Bontempo, A., et al. (2016). Influência de bioestimulantes e nutrientes na emergência e no crescimento inicial de feijão, soja e milho. *Revista Brasileira de Milho e Sorgo*, 15(1), 86–93. <https://doi.org/10.18512/1980-6477/rbms.v15n1p86-93>
- Galbiatti, J. A., et al. (2004). Efeito de diferentes períodos de irrigação no desenvolvimento, produção e qualidade de sementes na cultura do milho (*Zea mays L.*). *Engenharia Agrícola*, 24, 301–308.
- Governo do Paraná. (2024). *Paraná deve produzir 21,12 milhões de toneladas de grãos na safra de verão 2023/2024*. Agência Estadual de Notícias. Agência Estadual de Notícias do Paraná
- Guimarães, L. J. M. (2024). *Dia Nacional do Milho – A importância do milho para o agronegócio brasileiro*. EMBRAPA. EMBRAPA Notícias.
- Koppert. (2022). *Acadian*. Koppert Brasil
- MAPA – Ministério da Agricultura e Pecuária. (2025). *Projeções do agronegócio brasileiro 2024/2025*. MAPA.
- Martins, D. C., et al. (2016). Produtividade de duas cultivares de milho submetidas ao tratamento de sementes com bioestimulantes, fertilizantes líquidos e *Azospirillum sp.* *Revista Brasileira de Milho e Sorgo*, 15(2), 217–228.
- Matsuoka, Y., Vigouroux, Y., Goodman, M. M., González-Sánchez, J., Buckler, E. S., & Doebley, J. F. (2002). A single domestication for maize shown by multilocus microsatellite genotyping. *Proceedings of the National Academy of Sciences of the United States of America*, 99, 6080–6084. <https://doi.org/10.1073/pnas.052125199>
- Mukherjee, A., & Patel, J. S. (2019). Seaweed extract: Biostimulator of plant defense and plant productivity. *International Journal of Environmental Science and Technology*, 17, 553–558. <https://doi.org/10.1007/S13762-019-02442-Z>
- Pereira, A. S. et al. (2018). Metodologia da pesquisa científica. [free ebook]. Santa Maria: Editora da UFSM.
- Prada Neto, I., et al. (2010). Efeitos de bioestimulantes, aplicados via semente, na cultura do milho (*Zea mays L.*). In *Congresso Nacional de Milho e Sorgo* (28., Goiânia, GO). Associação Brasileira de Milho e Sorgo.
- Risemberg, R. I. C. et al. (2026). A importância da metodologia científica no desenvolvimento de artigos científicos. *E-Acadêmica*, 7(1), e0171675. <https://eacademica.org/eacademica/article/view/675>.

Santos, V. M., Melo, A. V., Cardoso, D. P., Gonçalves, A. H., Varanda, M. A. F., & Taubinger, M. (2013). Uso de bioestimulantes no crescimento de plantas de *Zea mays* L. *Revista Brasileira de Milho e Sorgo*, 12(3), 307–318. <https://doi.org/10.18512/1980-6477/rbms.v12n3p307-318>

Shitsuka, R. et al. (2014). *Matemática fundamental para tecnologia*. (2nd Ed.). Editora Érica.

Silva, A. R., Cunha, G., & Silva, J. P. R. (2022). Algas proporcionam tolerância ao estresse hídrico no milho. *Revista Campo & Negócios*. Revista Campo & Negócios

Silva, S., et al. (2021). Parâmetros produtivos do milho sob déficit hídrico em diferentes fases fenológicas no semiárido brasileiro. *Irriga*, 1(1), 30–41. *Revista Irriga*

Silva, T. A. P. (2018). Uso de biofertilizantes (extrato de algas – *Ascophyllum nodosum*) na cultura do milho. *Informativo Técnico Nortox* (Ed. 05, pp. 1–4). Nortox Informativo Técnico

Toledo, L. R. (2024). Clima desafia, mas preços do milho aliviam produtores no Paraná. *Canal Rural*. Canal Rural

Wurlitzer, R., & Simonetti, A. P. M. M. (2024). Efeitos da aplicação da alga *Ascophyllum nodosum* no desenvolvimento e produção da cultura da soja. *Revista Thêma et Scientia*, 14(2), 256–266.

Zottis, R. (2023). Os impactos dos estresses ambientais na produção de milho. *Brevant*. Brevant Brasil.