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Original Article

Remote sensing in maize: effect of vegetal biostimulants application in three stages of development

Sensoriamento remoto em milho: efeito da aplicação de bioestimulantes vegetais em três fases de desenvolvimento

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Abstract

Maize is a crop of global economic importance and is widely cultivated throughout the Brazilian territory. The use of biostimulants can increase yield and improve crop yield. Unmanned aerial vehicles can be employed in arable areas, allowing their use in an economically way. This study to evaluate the use of biostimulant and the best application timing using photogrammetric indexes in maize, and indicate the most suitable plant index for yield increase through a Pearson's correlation. The DJI Drone coupled with RGB camera was used, and the images were processed through the AgisoftPhotoscan® software to generate the orthomosaic, and the QGIS® software version 3.4.15 with GRASS was used to generate thematic maps with the classification of the indexes of vegetation (NGRDI, EXG, SAVI, TGI, GLI, RI). A matrix of Pearson correlation coefficients between the variables was also created, and the results were analyzed with the R software. In general, the products Pyroligneous Extract (PE) and the hormonal product (HP) were the best for the two seasons studied. However, the HP was the best product to mitigate plant water stress in the dry period. Application at phenological stage V3 showed the lowest growth in the rainy season and in application to the seeds in the dry season. Dose 4 of the pyroligneous extract increased productivity in the rainy season and level 3.4 for the hormone product. Among the indexes evaluated, only the SAVI index showed significant differences between the others and showed significance for productivity in the two periods.

Keywords: *Zea mays*, bioregulators, vegetation index.

Resumo

O milho é uma cultura de importância econômica mundial e é amplamente cultivada em todo o território brasileiro. O uso de bioestimulantes pode aumentar e melhorar o rendimento das culturas. Veículos aéreos não tripulados podem ser empregados em campos aráveis, permitindo sua utilização de forma econômica. Objetivou-se avaliar o uso de bioestimulante e a melhor época de aplicação utilizando índices fotogramétricos em milho e indicar o índice de planta mais adequado para aumento de produtividade através da correlação de Pearson. Foi utilizado o Drone DJI acoplado com câmera RGB, e as imagens foram processadas através do software AgisoftPhotoscan® para geração do ortomosaico, e o software QGIS® versão 3.4.15 com GRASS foi utilizado para geração de mapas temáticos com a classificação dos índices de vegetação (NGRDI, ExG, SAVI, TGI, GLI, RI). Também foi criada uma matriz de coeficientes de correlação de Pearson entre as variáveis, e os resultados foram analisados com o software R. De modo geral, os produtos Extrato Pirolenhoso (PE) e Produto Hormonal (HP) foram os melhores para as duas épocas estudadas. Entretanto, o HP foi o melhor produto para mitigar o estresse hídrico das plantas no período seco. A aplicação no estádio fenológico V3 apresentou menor crescimento no período chuvoso e a aplicação nas sementes no período seco. A dose 4 do extrato pirolenhoso aumentou a produtividade no período chuvoso e o nível 3,4 para o produto hormonal. Dentre os índices avaliados, apenas o índice SAVI apresentou diferenças significativas entre os demais e mostrou significância para a produtividade nos dois períodos.

Palavras-chave: *Zea mays*, biorreguladores, índice de vegetação

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1. Introduction

Maize (*Zea mays* L.) is a widely cultivated crop with significant economic and social importance. It can have many uses, including animal and human consumption, manufacturing and energy supply, as a biofuel and production of silage with its green mass. Another important factor related to maize cultivation is that 56% of its total production comes from small farmers, thus providing employment and income for many families (Sordi et al., 2020).

Brazil stands as the third largest maize producer in the global rank. This crop is among the country's most cultivated, making it one of the main agricultural "commodities", considered the second grain of greater social and economic relevance. The 2019/2020 harvest reached 102.5 million tons of grains, with an average productivity of 5.53 t ha^{-1} and 18.5 million hectares of the cultivated area (CONAB, 2020).

These high yields result from several studies focused on optimizing yield increase through products that stimulate the growth and development of plants, such as biostimulants. Which are substances created by mixing two or more plant bioregulator products or other natural or synthetic substances (nutrients, vitamins, and amino acids), which can be applied via seed or foliar applications (Santos et al. 2020). These products act on the physiological processes of plants, aid plant development and nutrient absorption, promote hormonal balance and stimulate favorable responses to biotic and/or abiotic factors (Calvo et al., 2014).

Biostimulants can also be known by other names, depending on the manufacturer, where in some cases, the term biostimulant does not appear. Instead, the product is referred to as bioregulators, additives, plant regulators, or growth promoters. According to Law No. 6.894 of December 16, 1980 and MAPA, through Normative Instruction No. 61 of July 18, 2020, these products are classified as biofertilizers (Brazil, 2020).

Another factor contributing to higher yields is the use of new technologies, such as remote sensing systems. This tool aids the monitoring and management of large agricultural areas by gathering fast and accurate information. This is very relevant, especially when cultivating short-cycle crops, such as maize (Kalisch et al., 2020). These systems can capture images of large areas, which after processing, aid in decisions. Through these tools, it is possible to evaluate water and physiological conditions, soil erosion processes, weed identification, and other aspects with less cost and time than traditional practices.

The use of unmanned aerial vehicles (UAVs) is mainly applied due to their reduced operating costs and allowing for flights with low altitudes, which provide high-resolution images. With this, it is possible to study several vegetation indexes based on visible aspects (RGB), obtaining an interaction between the vegetation under study and the electromagnetic energy in the red and near-infrared wavelengths (Abrantes, 2019).

Therefore, the present research aimed to find the best plant biostimulant product, the best level (dose), and stage for application using the photogrammetric plant indexes in maize and to indicate the plant index related to productivity increase by Pearson's correlation.

2. Materials and methods

2.1. Location of the study

The experiments were carried out in 2020 during the rainy season (04/14 to 08/20/2020) and the dry season (07/30 to 12/03/2020, nearby each other), at the Chã-de-Jardim Experimental Farm (06° 57' 46" S and 35° 41' 31" W and altitude of 600 m) at the Agricultural Sciences Center of the Universidade Federal da Paraíba, in the municipality of Areia, Paraíba, Brazil, located in the geographic microregion of the Brejo Paraibano.

2.2. Soil physicochemical properties analysis

For the chemical and physical characterization of the experimental area and the recommendation of fertilizants application, soil samples were collected from the 0-20 cm layer and then mixed into a single sample for subsequent soil analysis at the Laboratory of Soil Fertility at the Universidade Federal da Paraíba (Table 1).

2.3. Edaphoclimatic conditions

The soils of the experimental site were classified as Typical Dystrophic Yellow Latosol, with textural characteristic loamy clayey (Santos et al., 2020), with 320 g kg^{-1} of clay, 93 g kg^{-1} of silt, and 587 g kg^{-1} of sand. The climate of the region is classified as As', hot and humid according to the Köppen classification, with autumn-winter rains and average annual precipitation of 1.200 to 1.400 mm, with more than 75% concentrated in April-July, annual average temperature oscillating between 22 and 26 ºC and relative humidity between 75 and 87% (Ribeiro et al. 2018). During the experiments, daily data on rainfall (mm), maximum and minimum air temperature, and relative air humidity were recorded (Figure 1).

2.4. Experimental design

A complete randomized block design was used (DBC) with four replications, in a factorial scheme (3 × 4 × 3)

Table 1. Physicochemical properties of the soil of the Chã-de-Jardim Experimental farm, Areia, Paraíba, Brazil, 2020.

Season	pH	P	K^+	Na^+	H^++Al^{+3}	Al^{+3}	Ca^{+2}	Mg^{+2}	SB	CTC	MO
	H_2O	--mg dm^{-3}--		-------------------------cmolc dm^{-3}----------------------							g kg^{-1}
Rainy	6.3	2.46	56.80	0.04	4.95	0.05	3.97	2.04	6.19	11.14	29.79
Dry	6.0	2.20	44.14	0.05	4.50	0.05	3.91	1.45	5.52	10.02	33.62

Source: Authors, 2022.

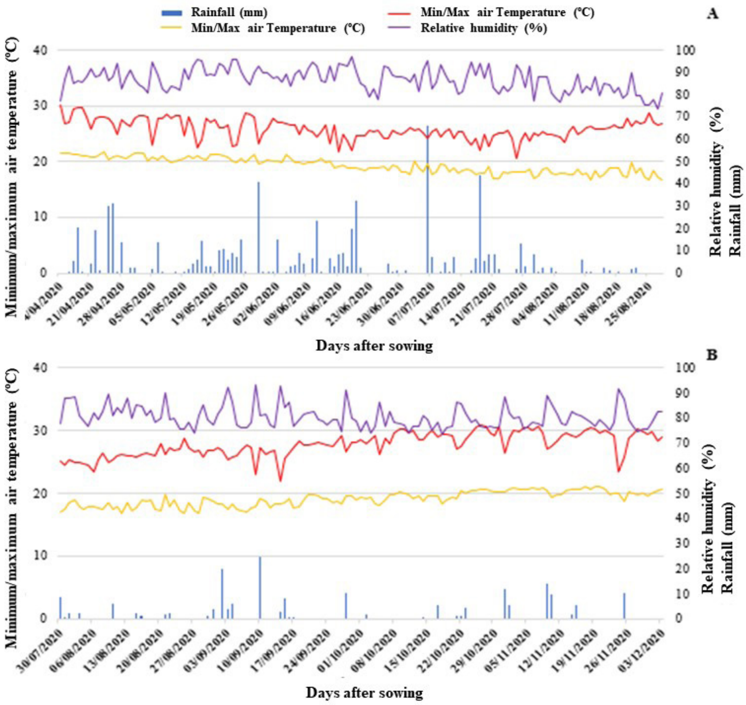

Figure 1. Daily average precipitation, maximum and minimum air temperature, and relative humidity in the rainy (A) and dry seasons (B). **Source:** Authors, 2022.

+ 1 (control), with three products: pyroligneous extract (5.3, 10.6. 15.9 and 21.2 L ha^{-1}), algae extract (0.25, 0.50, 0.75 and 1.0 kg ha^{-1}) and hormone product (150, 300, 450 and 600 mL ha^{-1}), four levels (doses) of each product and three times of application of the products (seed, V3, and V8), applied in equal proportions in the three stages.

Each plot consisted of 5 lines (rows) of corn with 5.0 meters length, 0.5 m between lines, and 0.5 m at the ends. Thus, the useful area of the plot was 4.0 m^2 in a total area of 1920 m^2.

For the standardization of tables and regression graphs, levels (0, 1, 2, 3, and 4) were applied to represent the doses due to different doses of different products.

The products were applied from 16:00, according to the recommendation to reduce losses. The application was manual, using a backpack sprayer with a capacity of 20 liters. The products were applied directly to the seeds at sowing, and at the V3 and V8 stages, the products were foliar applied.

Each product used in the present research has different compositions, they are considered plant biostimulants, and their use in agriculture is of paramount importance. The composition of the products is shown in Table 2.

2.5. Agronomic management

The soil was plowed, harrowed, and fertilized according to the soil analysis recommendations (Table 1).

Sixty (60) kg N ha^{-1} via urea (45% N) was used for fertilization, 50% on the foundation and 50% in the top-dressing 45 days after sowing, 40 kg KCl ha^{-1} via potassium chloride (48% KCl) and 60 kg P_2O_5 ha^{-1} via single superphosphate (18% P_2O_5).

The Hybrid AG1051 (Monsanto®) maize cultivar was used. This cultivar has an early cycle, small size, and hard and orange grains.

Weed management was made manually, and the insecticide Decis 25 CE was applied at a dose of 15 L ha^{-1} to control the armyworm.

2.6. Reflectance index

Aerial images were obtained by drone, Unmanned Aerial Vehicle (UAV), DJI® brand, Phantom 4 model, and its attached camera, set to capture images in the visible range (RGB).

The images were collected during the phenological start of flowering. The flights were performed 60 days after planting. The images were taken in the north-south direction of the experimental plots, between 11:00 AM and 12:00 AM, to avoid radiometric differences, to avoid errors. The photos were processed using the AgisoftPhotoscan® software to generate the ortho-mosaic, according to the following procedure:

I. The images were imported, with their respective altitude angles, determined by the inertial navigation system (IMU).
II. Image alignment: the characteristics and corresponding descriptors between the images (Geotags) were extracted. The positions of the images were calculated among themselves (relative external orientation) and to the landscape (absolute external orientation), and then the sparse point cloud model was determined.
III. Dense point cloud: based on the estimated positions of the images and the sparse points, new depth points

Table 2. Composition of the biostimulant products.

Pyroligneous Extract (*Eucalyptus grandis*)			
Syringol	8.46%	2-acetylfuran	3.12%
Gauiacol	14.36%	4-methyl-2.6-dimethoxy-phenol	2.52%
Furfural	15.62%	5- methyl -2-furancarboxaldehyde	4.20%
Creosol	4.87%	2-cyclopentene-1-1	2.27%
Ciclopentane	1.64%	2- methyl -2-cyclopentene-1-1	2.9%
Phenol	1.43%	3- methyl -1.2- cyclopentanedione	2.25%
Hydrazone	2.29%	4-ethyl-2-methoxy-phenol	2.61%
Hydroquinone	0.10%	2-(methoxymethyl)-furan	0.48%
Acetic acid	22.34%	N-nitrosodimethylamine	0.41%
Acetophenone	0.17%	1.2.3-trimethoxy-5-methyl-benzene	1.64%
Methyl benzoate	0.23%	1-hydroxi-2-butanone	1.85%
Butyrolactone	0.39%	Other	3.85%
Algae extract (*Ascophyllum nodosum*)			
Variables		**Aminoacids (1.01%)**	
Calcium (Ca)	0.16%	Aspartic acid	0.14%
Sulfur (S)	0.52%	Glutamic acid	0.20%
Phosphate (P_2O_5)	0.08%	Alanine	0.08%
Magnesium (Mg)	0.08%	Phenylalanine	0.07%
Organic Matter	16.00%	Glycine	0.06%
Total Nitrogen (N)	0.60%	Isoleucine	0.07%
Potassium (K_2O)	7.00%	Leucine	0.09%
Sodium (Na)	1.20%	Lysin	0.05%
Iron (Fe)	0.006%	Methionine	0.03%
Cupper (Cu)	0.0005%	Proline	0.07%
Zinc (Zn)	0.0015%	Tyrosine	0.06%
Manganese (Mn)	0.0005%	Tryptophan	0.02%
Boron (B)	0.005%	Valine	0.07%
Carbohydrates		Alginic Acid. mannitol. laminarin.	

Hormonal product	
N6-furfuryladenine (Kinetin)	**0.0009% m/v**
(3S.3aS.4S.4aS.7S.9aR.9bR.12S) – 7.12-dihydroxy- 3-methyl-6-methylene-2-oxoperhydro- 4a.7-methano-9b.3-propenoazuleno [1.2-b] furan-4-carboxylic acid (Gibberelic acid as GA3	0.005% m/v
4-(indol-3-yl)butyric acid (4-INDOL-3-BUTIRIC-ACID)	0.005% m/v
Inert ingredients	99.98% m/v

Sources: Authors, 2022. Analysis performed at Universidade Federal de Viçosa - UFV, Viçosa-MG, Brazil.

were determined. Subsequently, these new points were combined into a dense point cloud;

IV. Construction of the orthophoto mosaic: the orthomosaic was exported in the Universal Transverse Mercator (UTM) coordinate system, Zone 22 S, in the WGS84 reference system, with a spatial resolution of 3 cm. The ND value of the output pixel was obtained by calculating the average of the superimposed values;

V. Export of the orthophoto mosaic: the orthomosaic of the experimental area was exported in Geotiff format, with the same reference system and cartographic projection.

The orthomosaic, which resulted from the final joining of images, was worked on QGIS® 3.4.15 with GRASS to generate thematic maps with the classification of vegetation indexes.

The methodology of the indexes consisted of reading the RGB (red, green, and blue) reflection wavelengths of the leaf, which were submitted to consolidated equations (Table 3), to generate values that correspond to the healthy crop. These indexes were calculated using QGIS 3.10.11 using raster calculations.

2.7. Statistical analysis

Data were submitted to analysis of variance (ANOVA), and the means were compared by Tukey's test ($p \leq 0.05$). Data was also submitted to regression analysis. A matrix of Pearson's correlation coefficients (r) between the variables under study was also used, and the significance of r was verified using Student's t-test at 5%. All analyses were performed using the R statistical software 3.6.1. (R Core Team, 2019).

3. Results

In the rainy season, an interaction between the individual factors (Products, Levels, and stages) and double interactions (Product × Levels, Products × Phases, and Levels × Phases) was observed, with statistically significant values ($p \leq 0.01$) for all the variables studied (Table 4). For the dry period, no significant interaction was observed for the individual factor Product (in the variables NGRDI, ExG, SAVI, and GLI) and the interactions between Product x stages (in the SAVI index) and Product × Levels × stages, with a significant effect for the remaining factors and variables.

For the NGRDI variable, the best applied product was the pyroligneous extract (EP) both in the dry and rainy periods (Table 5). The same conclusion can be drawn for ExG, where EP showed superior results compared to other products. A similar trend is also observed at level 4 of the TGI variable during the rainy period, with the pyroligneous extract still being the best product. The same occurred for the GLI variable at levels 1 and 3, for both periods studied.

For the variable SAVI, there was only an effect of products at levels 2 and 3 in the rainy season and 1, 3, and 4 in the dry season. For this variable, the best product for both periods was the commercial product (HP). The same occurred for level 2 in the TGI, where this product was superior to the algae extract (AE) in the two seasons studied, at levels 2 and 4 for the GLI and level 3 in the RI variable.

For the TGI and RI, the algae extract promoted higher results at levels 1 and 3 and 1, 2, and 4 during the two seasons.

In the regression analysis, some divergences are observed when comparing the rainy season (Figure 2) and the dry season (Figure 3). In the Products x Levels interaction, these differences are related to the behavior of the graphs and the results obtained in the two seasons.

A quadratic behavior was observed for all products on the NGRDI, ExG, and TGI index and PE and HP in the SAVI and GLI index during the rainy season (Figure 2A). In the rainy season, an increasing linear behavior was observed for the SAVI and GLI index, both in HP, and a decreasing linear behavior for the RI index for the three products.

Evaluating the best levels of products and their effects on the NGRDI (Figure 2A) during the rainy season, it was possible to verify that the PE promoted an index of 0.1504 at level 4 (dose 4), with an increase of 19% compared to the control. In the AE, an index of 0.1509 was obtained with an increase of 20.82% in dose 4. For the HP, the increase was 15.55%, at level 2.4, reaching a value of 0.14638.

The ExG index, the best levels were 3.6, 2.6, and 2.6, with the PE, AE, and HP, reaching index values of 61.50; 61.56, and 60.60, representing increments of 20.97%; 20.20%, and 19.18%, respectively (Figure 2B).

SAVI (Figure 2C), the best levels were 4.4 and 2.3 for PE, AE, and HP, respectively, reaching index levels of 0.2235; 0.2204; and 0.22046 with an increase of 13.85%; 13.37%, and 12.42% compared to the control (zero level - dose-zero).

For the TGI, according to the quadratic equations, the higher performance was observed at levels 5.3 (PE); 2.5 (AE), and 2.8 (HP), with a significant increase of 18.45%; 15.14%, and 13.43%, representing increments of 31.45%; 31.03%; and 30.24%, respectively (Figure 2D).

A quadratic behavior was observed for In the GLI index (Figure 2E) under treatment with PE and HP and an increasing linear behavior for the AE. Treatment with PE at level 3 promoted the highest index value (30.15), with an increase of 12.47% compared to the control. Treatment with HP at the same level resulted in an increment of 12.27%, with an index of 29.79. For the AE, the GLI index increased linearly as the level increased. The highest level promoted a value of 30.16 and an increase of 12.30% compared to the control. In the RI, all products showed a decreasing linear behavior as the levels increased (Figure 2F).

In the dry season, the HP promoted a quadratic behavior with an upward concavity in the NGRDI and RI indexes (Figure 3). The PE also showed a quadratic, downward

Table 3. Vegetal indexes used in the study.

Index name	Code	Formula*	References
Normalized green-red difference index	NGRDI	(G-R) /(G+R)	Yang et al. (2008)
Excess green index	EXG	(2 X G) -R-B/(R+G+B)	Woebbecke et al. (1995)
Soil adjusted vegetation index	(SAVI) adaptado	((1 + L) * (G – R)) / (L + G + R)	Magalhães et al. (2019)
Triangular greenness index	TGI	G - 0.39 * R - 0.61 * B	Hunt Júnior et al. (2005)
Ground level image analysis	GLI	((G-R) + (G-B))/(R+G+B)	Louhaichi et al. (2001)
Redness index	RI	(R-G)/(R+G)	Huete and Escadafal (1991)

*R = red, G = green, B = blue, L = green covered area.
Source: Authors, 2022

Table 4. Analysis of variance for the Normalized Green-Red Difference Index (NGRDI), Ex-cess Green Index (ExG), Soil Adjusted Vegetation Index (SAVI), Triangular Greenness Index (TGI), Ground Level Image Analysis (GLI), Redness Index (RI) and Yield (YLD) in the Rainy and Dry season.

SV	GL	Mean square						YLD
		NGRDI	**ExG**	**SAVI**	**TGI**	**GLI**	**RI**	
		Rainy season						
Products (P)	2	0.00045**	7.72**	0.00052**	3.85**	5.64**	0.000004**	3867902.05**
Levels (N)	4	0.00249 **	609.78**	0.00335**	91.41**	55.22**	0.000022**	2067834.04**
Stage (S)	2	0.00059**	5.81**	0.00204**	2.64**	1.13**	0.000001**	100303.78**
P x N	8	0.00098**	66.59**	0.00173**	15.34**	16.31**	0.000006**	645202.06**
P x S	4	0.00212**	136.75**	0.00463**	36.35**	42.41**	0.000003**	175643.56**
N x S	8	0.00038**	43.95**	0.00100**	11.12**	7.25**	0.000001**	648560.39**
Px NxS	16	0.00162^{NS}	66.28^{NS}	0.00329^{NS}	17.49^{NS}	18.04^{NS}	0.000002^{NS}	1396056.05^{NS}
Block	3	0.00013^{NS}	0.13^{NS}	0.00009^{NS}	0.50 ^{NS}	0.49^{NS}	0.0000001^{NS}	9683249**
Error	132	0.00008	0.16	0.00008	0.21	0.23	0.00000007	11114.35
CV (%)		6.70	0.71	4.40	1.60	1.69	13.50	3.78
		Dry season						
Products (P)	2	0.00003^{NS}	0.34^{NS}	0.00009 ^{NS}	12.45**	0.47^{NS}	0.00018**	1111791.82**
Levels (N)	4	0.00771**	54.74**	0.00385**	196.48**	51.80**	0.000078**	9630348.61**
Stage (S)	2	0.00162**	22.74**	0.00055**	46.67**	24.76**	0.00000 ^{NS}	7936610.47**
P x N	8	0.00119**	15.07**	0.00091**	22.93**	14.28**	0.00008**	305178.15**
P x S	4	0.00008**	1.72**	0.00009 ^{NS}	1.23**	2.14**	0.000045**	470380.16**
N x S	8	0.00274**	20.85**	0.00072**	27.11**	20.22**	0.000047**	527143.38**
P x N x S	16	0.00309^{NS}	23.35^{NS}	0.00119^{NS}	18.71^{NS}	22.69^{NS}	0.000049^{NS}	12878088^{NS}
Block	3	0.00008**	0.25 ^{NS}	0.00014 ^{NS}	1.81**	0.55^{NS}	0.000001 ^{NS}	2522.10^{NS}
Error	132	0.00002	0.25	0.00008	0.25	0.25	0.000001	8442.73
CV (%)		1.94	2.20	6.45	1.75	2.20	13.99	

** Significant at 1% probability by the F test. SV: Source of variation; NS = not significant.
Source: Authors, 2022.

concavity behavior. Differently, the ExG, SAVI, TGI, and GLI indexes, showed a decreasing linear behavior for all products. In the NGRDI index, a decreasing linear behavior was observed for the PE and AE, and an increasing linear behavior for HP in the RI index.

Except for the NGRDI and RI (Figure 3A and 3F), the ExG, SAVI, TGI, and GLI (Figure 3B; 3C; 3D and 3E) indexes showed a decreasing linear behavior as the levels (dose) increased in the dry season. For the NGRDI, treatment with PE and AE showed a decreasing linear behavior, while the treatment with HP promoted a quadratic behavior with facing up concavity.

The variable RI (Figure 3F), the three products showed efficiency, and the PE promoted a quadratic behavior with facing up concavity. A decrease in the RI was observed, but at level 2, this index reverted the stress, increasing the index values as the level increased. In the AE, the 1.5 dose promoted an increment of 37.5% compared to the control. On the other hand, the application of HP attenuated plant stress, showing an increase in the index value as the levels increased.

The interaction Products x Stage, a significant effect in the two seasons was observed (Table 6). During the rainy season, PE and HP showed higher values of NGRDI when applied via seeds. Even in the rainy season, the V8 phenological stage showed a better index value when submitted to treatment with PE and AE. In the dry season, the V3 and V8 stages responded well to the application of all products.

The ExG, the best values were observed in the V8 phenological stage, during the rainy season, in plants treated with PE and AE, with no statistical difference from the seed treatment with PE. In the dry season, the V8 stage showed higher values under treatment with all products, except for the HP in the V3 phenological stage. The best product in the rainy season was the HP applied in the seeds and on V3 plants and AE in the V8. PH and AE provided the best results in the V3 and V8 phenological stages in the dry season, respectively.

SAVI, the EP was superior to the other products when applied to the seeds in the rainy season, the HP was better in the V3 stage, and the AE in V8 plants. In the dry

Table 5. Mean values of product x dose interaction for Normalized Green-Red Difference Index (NGDRI), Excess Green Index (ExG), Soil Adjusted Vegetation Index (SAVI), Triangular Greenness Index (TGI), Ground Level Image Analysis (GLI), and Redness Index (RI) in the Rainy and Dry season.

Products	**Levels**				
	0	**1**	**2**	**3**	**4**
			Rainy season		
			NGRDI		
Pyroligneous extract	0.1257 a	0.1404 a	0.1527 a	0.1537 a	0.1503 a
Algae extract	0.1257 a	0.1262 b	0.1344 b	0.1419 b	0.1483 ab
Hormonal product	0.1257 a	0.1378 a	0.1574 a	0.1309 c	0.1411 b
			EXG		
Pyroligneous extract	50.608 a	59.403 a	63.83 a	61.427 a	61.382 a
Algae extract	50.608 a	56.602 b	59.450 b	61.665 a	58.545 c
Hormonal product	50.608 a	56.040 c	58.638 c	56.151 b	59.551 b
			SAVI		
Pyroligneous extract	0.1948 a	0.2131 a	0.2104 b	0.1975 c	0.2228 a
Algae extract	0.1948 a	0.2045 a	0.2004 c	0.2153 b	0.2219 a
Hormonal product	0.1948 a	0.2092 a	0.2383 a	0.2251 a	0.2143 a
			TGI		
Pyroligneous extract	26.77 a	27.73 b	29.66 c	30.86 a	30.96 a
Algae extract	26.77 a	30.10 a	30.39 b	30.97 a	29.43 c
Hormonal product	26.77 a	27.87 b	31.82 a	28.55 b	30.17 b
			GLI		
Pyroligneous extract	26.61 a	30.09 a	28.63 b	29.88 a	29.45 b
Algae extract	26.61 a	28.39 b	27.97 c	29.35 b	29.51 b
Hormonal product	26.61 a	27.98 b	31.08 a	27.31 c	30.24 a
			RI		
Pyroligneous extract	0.0033 a	0.0019 a	0.0011 b	0.0018 b	0.0008 b
Algae extract	0.0033 a	00021 a	0.0032 a	0.0019 b	0.0015 a
Hormonal product	0.0033 a	0.0015 b	0.0006 c	0.0023 a	0.0015 a
			Dry season		
			NGRDI		
Pyroligneous extract	0.2362 a	0.2097 a	0.2232 a	0.2137 a	0.2116 a
Algae extract	0.2362 a	0.2007 b	0.2175 b	0.2211 a	0.1891 b
Hormonal product	0.2362 a	0.2132 a	0.2134 c	0.1956 c	0.2125 a
			EXG		
Pyroligneous extract	24.63 a	21.95 b	23.59 a	23.95 a	22.56 a
Algae extract	24.63 a	21.41 c	23.78 a	24.01 a	20.56 c
Hormonal product	24.63 a	23.48 a	23.04 b	20.65 b	22.43 a
			SAVI		
Pyroligneous extract	0.1595 a	0.1407 b	0.1518 a	0.1348 b	0.1330 ab
Algae extract	0.1595 a	0.1306 c	0.1484 a	0.1288 b	0.1244 b
Hormonal product	0.1595 a	0.1501 a	0.1466 a	0.1511 a	0.1419 a
			TGI		
Pyroligneous extract	32.61 a	26.73 b	29.91 ab	27.32 b	26.26 b
Algae extract	32.61 a	29.01 a	29.43 b	30.20 a	25.80 b
Hormonal product	32.61 a	25.92 c	30.05 a	26.75 c	28.79 a
			GLI		
Pyroligneous extract	24.64 a	23.03 a	23.29 b	23.93 a	21.56 b
Algae extract	24.64 a	21.42 b	23.13 b	22.04 b	20.81 c
Hormonal product	24.64 a	23.73 a	23.78 a	20.73 c	22.43 a
			RI		
Pyroligneous extract	0,00051 a	0,00046 b	0,00028 b	0,00052 b	0,00053 b
Algae extract	0,00051 a	0,00102 a	0,00058 a	0,00046 b	0,00144 a
Hormonal product	0,00051 a	0,00036 c	0,00059 a	0,00065 a	0,00060 b

Means followed by the same letter do not differ by the Tukey test at 5% probability.
Source: Authors, 2022

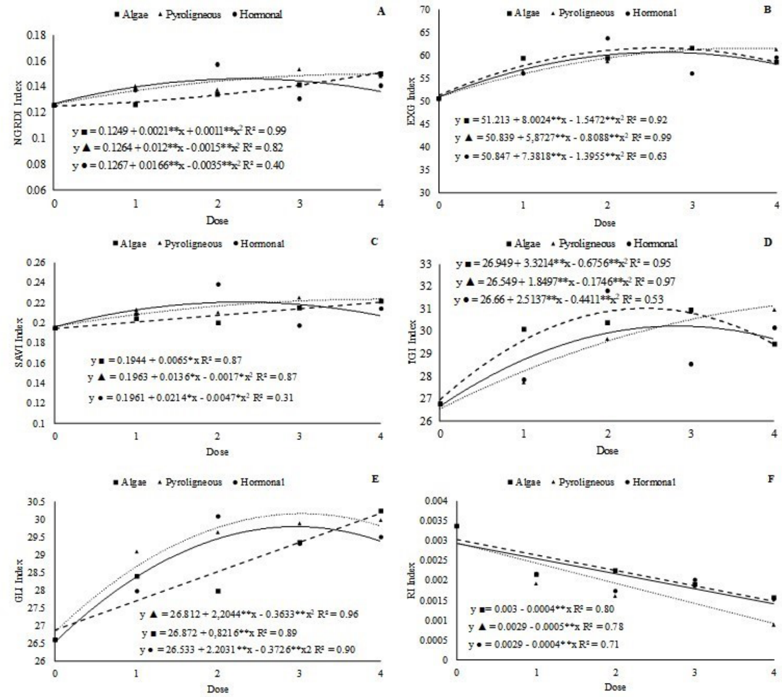

Figure 2. Normalized green-red difference index – NGRDI (A), Excess green index – ExG (B), Soil adjusted vegetation index – SAVI (C), Triangular greenness index – TGI (D), Ground level image analysis – GLI (E), and Redness index – RI (F) in response to levels (doses) of treatments applied during the rainy season. *, **: significant at 5% and 1%, respectively.

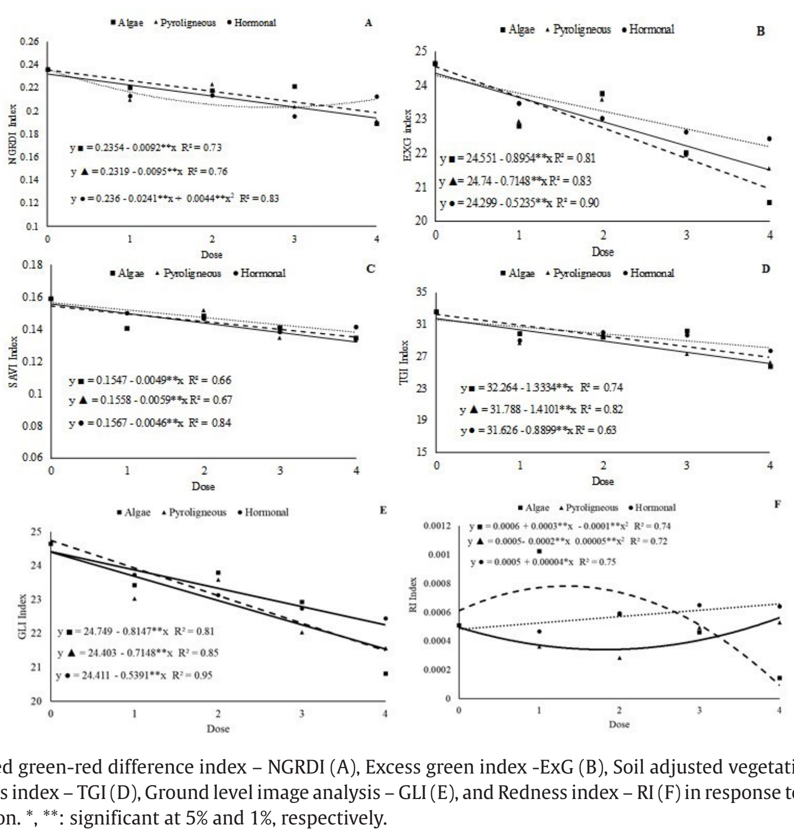

Figure 3. Normalized green-red difference index – NGRDI (A), Excess green index -ExG (B), Soil adjusted vegetation index – SAVI (C), Triangular greenness index – TGI (D), Ground level image analysis – GLI (E), and Redness index – RI (F) in response to treatments (doses) during the dry season. *, **: significant at 5% and 1%, respectively.

Table 6. Mean values of the interaction Products x Stage (phenological) for the Normalized Green-Red Difference Index (NGRDI), Excess Green Index (ExG), Soil Adjusted Vegetation Index (SAVI), Triangular Greenness Index (TGI), Ground Level Image Analysis (GLI), and Redness Index (RI) in the rainy and dry season.

Products	Stage			Stage		
	Seed	**V3**	**V8**	**Seed**	**V3**	**V8**
	NGRDI			**ExG**		
	Rainy season					
Pyroligneous extract	0.14838 aA	0.13326 aB	0.14292 aA	58.448 aA	56.319 cB	58.427 bA
Algae extract	0.12396 bC	0.13415 aB	0.14902 aA	55.958 bC	57.001 bB	60.816 aA
Hormonal product	0.14406 aA	0.13870 aAB	0.13302 bB	58.756 aA	58.539 aA	54.416 cB
	SAVI			TGI		
Pyroligneous extract	0.2278 aA	0.2009 bC	0.2111 bB	29.64 aA	28.39 cB	29.56 bA
Algae extract	0.1952 cB	0.2000 bB	0.2270 aA	28.74 bB	29.01 bB	30.85 aA
Hormonal product	0.2203 bA	0.2105 aB	0.2017 cC	29.98 aA	29.70 aA	27.42 cB
	GLI			RI		
Pyroligneous extract	29.27 bA	29.05 aAB	28.78 bB	0.0015 cB	0.0023 aA	0.0015 cB
Algae extract	27.11 cC	28.04 cB	30.38 aA	0.0025 aA	0.0025 aA	0.0019 bB
Hormonal product	29.65 aA	28.55 bB	27.30 cC	0.0019 bB	0.0018 bB	0.0023 aA
	Dry season					
	NGRDI			ExG		
Pyroligneous extract	0.2083 aB	0.2141 bA	0.2159 aA	22.43 aB	22.46 bB	23.32 bA
Algae extract	0.2049 bB	0.2155 abA	0.2163 aA	22.10 aC	22.82 abB	23.72 aA
Hormonal product	0.2088 aB	0.2178 aA	0.2183 aA	22.12 aB	23.11 aA	23.32 bA
	SAVI			TGI		
Pyroligneous extract	0.1394 aB	0.1452 aAB	0.1472 aA	27.87 bC	28.57 cB	29.25 bA
Algae extract	0.1408 aA	0.1432 aA	0.1443 aA	27.60 bB	29.22 bA	29.56 bA
Hormonal product	0.1414 aB	0.1496 aA	0.1451 aAB	28.37 aB	29.82 aA	30.13 aA
	GLI			RI		
Pyroligneous extract	22.43 aB	22.57 bB	23.32 bA	0.00036 bC	0.00058 bA	0.00048 cB
Algae extract	22.06 aC	22.92 bB	23.77 aA	0.00076 aB	0.00087 aA	0.00077 aB
Hormonal product	22.13 aB	23.31 aA	23.36 bA	0.00071 aA	0.00036 cC	0.00056 bB

Means followed by the same lowercase letter in the column and uppercase in the rows do not statistically differ by Tukey's test.
Source: Authors, 2022.

season, no significant effect of the products was observed. The phenological stages that showed a better response in the rainy season were PE and HP when applied to the seeds and V8 for AE, while in the dry season, the best responses were observed in V8 plants treated with PE and V3 when treated with HP.

The PE was superior to the AE when applied to the seeds on the TGI index during the rainy season. The AE promoted better response on V8 plats, and the HP provided better results in this variable when applied in the seed and on V3 plants. In the dry season, the product with the best performance was HP in all phenological stages studied. Overall, the V8 phenological stage showed superior performance in the rainy and dry seasons.

For the GLI, the PE promoted better results in the V3 stage, the AE in V8, and the HP when applied to the seeds. In the dry season, the AE promoted better results on V8 plants and the HP on V3 plants. In the rainy season, the best treatments were the PE and HP products applied to the seeds and AE when applied to plants at the V8 phenological stage. In the dry period, the V8 stage showed superior values for this variable.

The AE promoted the best results for RI in both seasons when applied to the seeds, at the V3 stage and in the V8 stage in the dry season. The best performance in both seasons was observed at the V3 stage. However, the phenological stage V8 provided better results when plants were treated with HP in the rainy season, while seed treatment provided superior values in the dry season.

Differences were observed between the two seasons through regression analysis for the interaction factor, Doses x Stages (Figure 4 and 5). A Quadratic behavior of the three

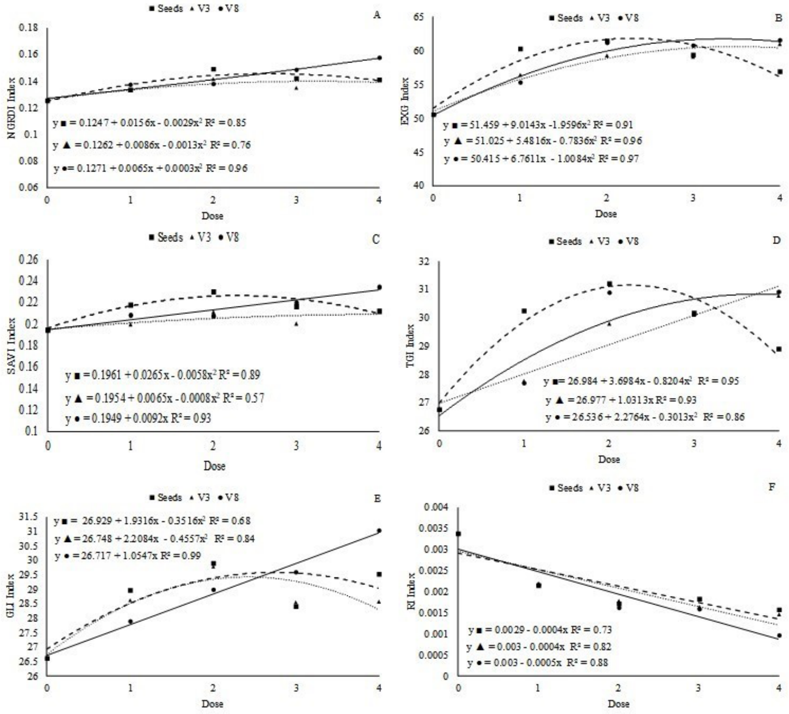

Figure 4. Normalized green-red difference index – NGRDI (A), Excess green index – ExG (B), Soil adjusted vegetation index – SAVI (C), Triangular greenness index – TGI (D), ground level image analysis – GLI (E), and Redness index – RI (F), in response to levels (doses) applied at different phenological stages during the rainy season. *, **: significant at 5% and 1%, respectively.

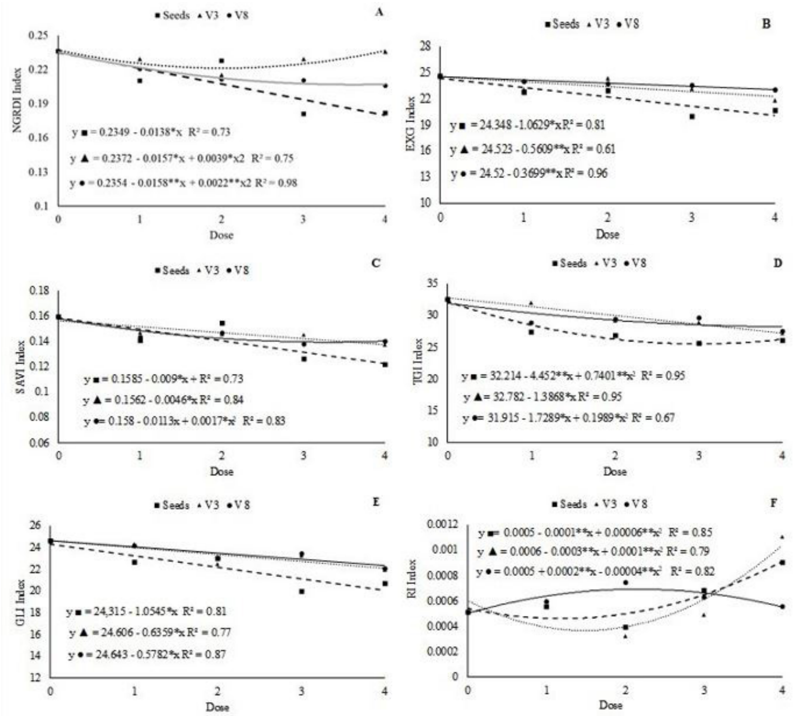

Figure 5. Normalized green-red difference index – NGRDI (A), Excess green index – ExG (B), Soil adjusted vegetation index – SAVI (C), Triangular greenness index – TGI (D), Ground level image analysis – GLI (E), and Redness index – RI (F), in response to the levels (doses) on different phenological stages in the dry season. *, **: significant at 5% e 1%, respectively.

phenological stages can be observed for the variables NGRDI and ExG in the rainy season (Figure 4A and 4B). A quadratic behavior was observed for treatments applied to seeds and V3 for the variables SAVI and GLI and linear season (Figure 4C and D). Behavior for plants treated at the V8 stage. For the TGI index (Figure 4E), quadratic behaviors were observed on treatments applied to the seed and at V8 and linear for plants treated at V3. The RI treatments on all phenological stages promoted the same decreasing linear behavior (Figure 4F).

The seed treatment promoted a value of 0.14568 for NGRDI, an increment of 16.82% compared to the control at level (dose) 2.7. In the phenological stage V3, an index value of 0.14288 was obtained, representing an increase of 13.22% at level 3.3, and in the V8 stage, an increase of 27.54% was obtained, at level 10 (according to the regression equation) with 0.1621 (Figure 4A).

For the ExG, (Figure 4B) the ideal levels were 2.3; 3.5, and 3.3 for treatment in the seeds, V3 and V8 phenological stage, with index values of 61.82; 60.61, and 61.74 and increments of 20.14%; 18.79% and 22.47%, respectively.

For the SAVI variable (Figure 4C), the best levels were 2.3; 4, and 4 for treatment in the seeds, V3 and V8 phenological stage, respectively, with index values of 0.22637; 0.2086; and 0.2317 representing a total increment of 15.85%; 6.75% and 18.88% when compared to the control (zero level).

Through quadratic equations and their derivatives, it was possible to verify the best levels for the TGI when treatments were applied to the seeds (2.3), V3 (4), and V8 (3.8) phenological stage, with a respective increment of 15.44%; 15.29% and 16.20%, when compared to the control (Figure 4D).

For the GLI, treatments applied to the seeds at level 2.7 promoted the highest index value (29.58), an increment of 9.85% compared to the control. In the phenological stage V3, the ideal level was 2.4, with an increment of 10% and an index value of 29.43. In the V8 stage, level 4 provided the higher increment (15.79%) with a value index of 30.93 (Figure 4E). For the RI, all phenological stages showed a decreasing linear behavior as the level increased (Figure 4F).

In the dry season, it is worth mentioning that the ExG and GLI indexes also showed a decreasing linear behavior as the levels increased (Figure 5).

For the NGRDI, treatments applied to the seeds promoted a decreasing linear behavior, reducing the index values as the level increased. The phenological stages V3 and V8 showed a quadratic behavior with the concavity facing upwards, and at levels 2 (V3) and 3.6 (V8), an index value of 0.2214 and 0.2070 were obtained, with a decrease of 6.66% and 12.05%, respectively, recovering after these levels (Figure 5A).

For the SAVI, only V8 showed a quadratic behavior, decreasing the index up to level 3.3, where the lowest index was observed (0.1392) with a decrease of 11.88% and recovering afterward (Figure 5C).

For the TGI (Figure 5D), the quadratic behavior was obtained in treatments applied to the seed, and V8 phenological stage, with the lowest indexes (32.14 and 28.15) obtained at levels 6 and 4.3, a decrease of 0.02 and 11.77%, respectively.

The three products promoted a quadratic behavior in the RI index. The seed and V3 stages resulted in an upward concavity graphic where the lowest values (0.0004584 and 0.000375) were obtained at levels 0.8 and 1.5, a decrease of 8.32% and 37.5%. However, the index values increased afterward, and at the last level (4), they reached the values of 0.00106 and 0.001, with significant increases of 112% and 66.67%. In the V8 stage, the concavity of the parabola is facing downwards and reached the highest value (2.5), with an index of 0.00075, an increase of 50%, compared to the control (Figure 5F).

Significant effects were obtained for the interaction factor Levels x stage in the rainy and dry seasons (Table 7). In general, the stage that resulted in the best NGRDI and ExG indexes, both in the rainy and dry seasons, was the V8 phenological stage.

For SAVI, treatment of the seeds promoted superior results than other phenological stages at levels 1, 2, and 3 in the rainy season and at levels 2 and 3 in the dry season. For level 4, the best phenological stage for treatment was V8 in both seasons.

In the TGI, a different response was observed in the rainy and dry seasons. In the rainy season for levels 1 and 2, the best phenological stages were the seed, and in level 3, no significant effect between the phenological stages was observed, while in the dry season, levels 1, 2, and 3 promoted better results when applied at the V8 phenological stage. At level 4, both periods behaved similarly, where V3 and V8 were superior to the seed phenological stage.

For the GLI, for levels 1, 3 and 4, in both seasons, the best parameters were obtained at V8. For level 2, there was a difference between the periods, where the rainy season provided better results than the dry season. The V8 was the crop's best phenological stage for applying the products studied.

For the RI in the rainy season, the best results were obtained in levels 1 and 3 at V3, and for level 4, the application to the seeds and V3 promoted superior results than when applied at V8. In the dry season, levels 1 and 4 promoted higher results when applied at V3 than in the other stages. At level 2, application at V8 was superior to the other stages, and at level 3, application to the seeds and at V8 was superior to V3.

For the isolate factor Product, without the SAVI index, there was a difference between the products applied in the rainy season and a not significant difference in the dry season (Figure 6A). However, a significant difference was obtained for the stages (Phenological stages) in both periods (Figure 6B).

Treatment with PE was superior to the AE in the rainy season and was not statistically from the HP (Figure 6A). The dry season had no significant effect on the products. For the phenological stage isolate factor (Figure 6B), the seed phenological stage was superior to the V3 phenological stage but did not differ from the V8 stage in the rainy season. In the dry season, the worst result was observed in the treatment of the seeds.

Significant effects can be observed both for the rainy season (Figure 7A) and dry season (Figure 8B) on productivity in response to the treatments at different

Table 7. Mean values of the interactions Stages x levels for Normalized green-red difference index (NGRDI), Excess green index (ExG), Soil adjusted vegetation index (SAVI), Triangular greenness index (TGI), Ground level image analysis (GLI), and Redness index (RI) in the rainy and dry season.

Stages	Levels				
	0	**1**	**2**	**3**	**4**
			NGRDI		
			Rainy season		
Seed	0.1257 a	0.1337 a	0.1383 b	0.1423 ab	0.1411 b
V3	0.1257 a	0.1331 a	0.1418 ab	0.1351 b	0.1409 b
V8	0.1257 a	0.1375 a	0.1493 a	0.1489 a	0.1577 a
			ExG		
Seed	50.608 a	55.361 c	61.453 a	59.360 b	56.948 c
V3	50.608 a	56.404 b	59.305 b	59.133 b	60.981 b
V8	50.608 a	60.279 a	61.162 a	60.751 a	61.551 a
			SAVI		
Seed	0.1948 a	0.2182 a	0.2300 a	0.2167 a	0.2124 b
V3	0.1948 a	0.2001 b	0.2115 b	0.2007 b	0.2118 b
V8	0.1948 a	0.2085 b	0.2077 b	0.2067 b	0.2348 a
			TGI		
Seed	26.77 a	30.24 a	31.20 a	30.17 a	28.89 b
V3	26.77 a	27.77 b	29.79 b	30.10 a	30.76 a
V8	26.77 a	27.69 b	29.89 b	30.11 a	30.91 a
			GLI		
Seed	26.61 a	28.96 b	29.91 a	28.41 b	29.52 b
V3	26.61 a	27.88 c	28.78 b	28.55 b	29.17 b
V8	26.61 a	29.62 a	29.00 b	29.59 a	31.03 a
			RI		
Seed	0.0033 a	0.0015 b	0.0016 a	0.0018 b	0.0015 a
V3	0.0033 a	0.0021 a	0.0017 a	0.0026 a	0.0014 a
V8	0.0033 a	0.0017 b	0.0016 a	0.0015 b	0.0009 b
			Dry season		
			NGRDI		
Seed	0.2361 a	0.2101 b	0.2112 c	0.1809 c	0.1819 b
V3	0.2361 a	0.1929 c	0.2152 b	0.2104 b	0.2056 a
V8	0.2361 a	0.2206 a	0.2277 a	0.2291 a	0.2059 a
			ExG		
Seed	24.63 a	22.77 b	22.98 b	19.99 b	20.71 b
V3	24.63 a	20.07 c	23.07 b	23.10 a	21.82 a
V8	24.63 a	24.00 a	24.36 a	23.52 a	22.02 a
			SAVI		
Seed	0.1595 a	0.1408 a	0.1545 a	0.1510 a	0.1220 b
V3	0.1595 a	0.1370 a	0.1455 b	0.1260 c	0.1272 b
V8	0.1595 a	0.1437 a	0.1459 b	0.1377 b	0.1401 a
			TGI		
Seed	32.61 a	27.49 b	27.89 c	25.68 c	26.05 b
V3	32.61 a	25.25 c	29.45 b	28.87 b	27.26 a
V8	32.61 a	28.92 a	32.04 a	29.72 a	27.54 a
			GLI		
Seed	24.64 a	22.69 b	22.98 b	19.99 b	20.71 b
V3	24.64 a	20.32 c	23.07 b	20.26 b	20.98 b
V8	24.64 a	24.16 a	24.45 a	23.44 a	22.11 a
			RI		
Seed	0.00051 a	0.00056 b	0.00039 b	0.00068 a	0.00091 b
V3	0.00051 a	0.00070 a	0.00032 b	0.00039 b	0.00110 a
V8	0.00051 a	0.00059 b	0.00074 a	0.00063 a	0.00056 c

Means followed by the same letter do not differ by the Tukey test.
Source: Authors, 2022

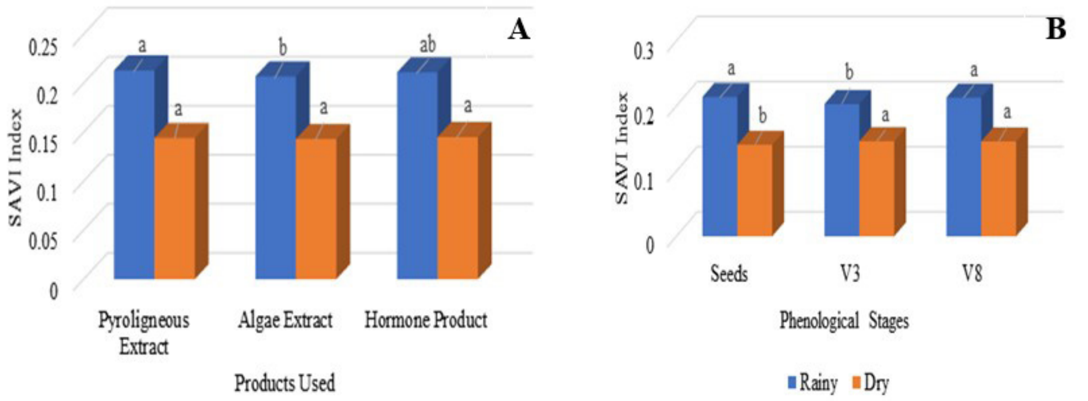

Figure 6. Mean values for the products treatments (A) and phenological stages (B) on the Soil Adjusted Vegetation Index (SAVI) in the rainy and dry season.

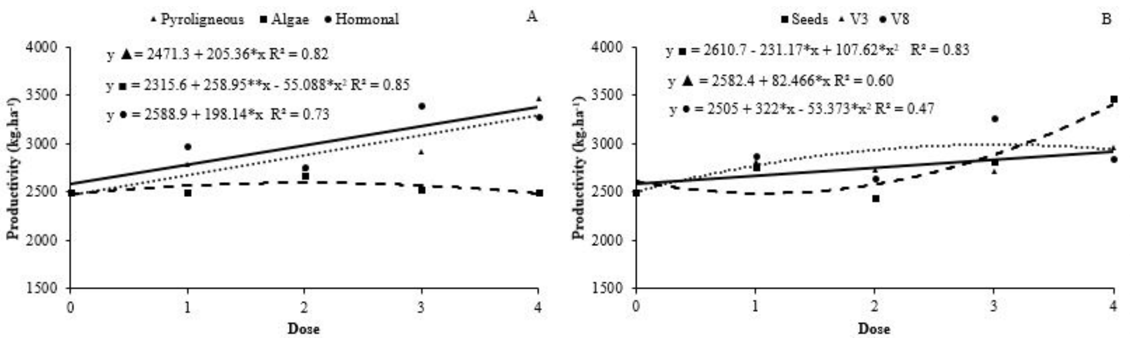

Figure 7. Productivity for different products (A) and stages (B) in response to treatments at different levels (doses) in the rainy season. *, **: significant at 5% and 1%, respectively.

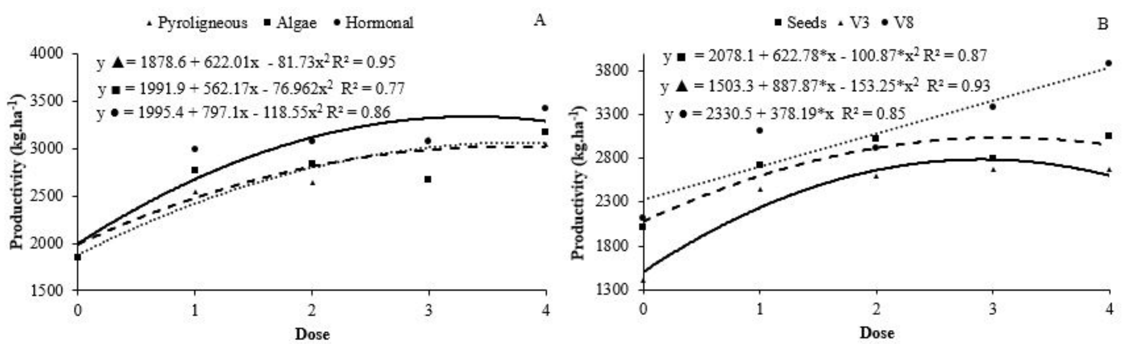

Figure 8. Productivity for different products (A) and stages (B) in response to treatments at different levels (doses) in the dry season. *, **: significant at 5% and 1%, respectively.

levels. In both seasons, the HP was superior to the other products. In the rainy season, this product promoted a linear-increasing behavior, reaching a productivity of 3.381.46 kg ha^{-1} at level 4, an increase of 30.61%, compared to the control (zero level). For the dry season, the best level was 3.36, which promoted productivity of 3.335.27 kg ha^{-1}, a 67.15% increase compared to the control.

The pyroligneous extract promoted a linear increasing behavior in the rainy season in the productivity at level 4, reaching 3.292.74 kg ha^{-1}, a 33.24% increase, compared to the control. In the dry season, the PE promoted a quadratic behavior of productivity, reaching a productivity of 3.062.05 kg ha^{-1}, at level 3.8, a 63% increase compared to the control.

Treatment with algae extract in the rainy season did not promote a difference in productivity with different levels (doses). Still, in the dry season, this product behaved in a significant and quadratic way, obtaining, at level 3.6, reaching a productivity of 3.018.28 kg ha^{-1}, a 51.5% increase compared to the control.

A significant effect of the productivity in response to the treatment with HP in different stages, in both seasons, except for the V3 stage, in the dry season, in which there was no significant effect between products (Table 8).

When the treatments PE and HP were applied to the seeds and at V8 in the rainy season, they were superior to the application at V3. As for the AE, applications at V3 and V8 stages were better than the seeds. For the dry season, the phenological stage V8 was the best for all products studied.

Significant effects on productivity in response to the application in the different phenological stages and levels were observed during the rainy (Figure 8A) and dry seasons (Figure 8B). When treatments were applied to the seeds, a quadratic (concavity upwards) behavior was observed in the rainy season and a quadratic concavity downwards in the dry season. In the rainy season, the best level was 4, which promoted productivity of 3407.94 kg ha^{-1}, a 30.5% increase compared to the control. In the dry season, the best level was 3.1, with a productivity of 3039.26 kg ha^{-1}, representing a 46.5% increase compared to the control.

An increasing linear behavior was observed on plants treated on V3 in the rainy season, where productivity increased as the level increased. In the dry season, a quadratic behavior was observed, and maximum productivity of 2789.29 kg ha^{-1} was obtained at level 2.9, an 85.5% increase compared to the control.

In the phenological stage V8, a quadratic behavior was observed during the rainy season, and at level 3, maximum productivity of 2.990.64 kg ha^{-1} was obtained. In the dry season, treatments at V8 promoted an increasing linear productivity with 3.843.26 kg ha^{-1}, with treatments applied in level 4 reaching a 64.9% increase compared to the control.

There was a highly significant correlation between NGRDI and SAVI (0.96) for both seasons studied (Table 9). In general, highly significant and positive correlations could be observed between the plant indexes studied, except for RI, as these had negative correlations in both seasons.

In the rainy season, significant effects were observed between the indexes and productivity, except for the TGI index. In the dry season, only the SAVI and TGI indexes positively affected productivity.

Table 8. Average values of Productivity in the rainy and dry periods according to the products and phases.

	Rainy season			**Dry season**		
	Seed	**V3**	**V8**	**Seed**	**V3**	**V8**
Pyroligneous extract	2946.47 bA	278.60 bB	2909.92 bA	2552.76 cB	2351.35 aC	2992.52 bA
Algae extract	2387.62 cB	2551.66 cA	2569.60 cA	2691.81 bB	2387.79 aC	2883.68 cA
Hormonal product	3048.02 aA	2900.59 aB	3006.77 aA	2910.80 aB	2339.53 aC	3384.60 aA

Means followed by the same lowercase letter in the column and uppercase letter in the rows do not statistically differ by the Tukey test.
Source: Authors, 2022.

Table 9. Pearson Correlation between vegetative indexes and productivity.

	Rainy season						
	NGRDI	**EXG**	**SAVI**	**TGI**	**GLI**	**RI**	**PROD**
NGRDI		0.71**	0.96**	0.67**	0.88**	-0.38**	0.32*
EXG			0.73**	0.97*	0.79**	-0.52**	0.30*
SAVI				0.71**	0.88**	-0.40**	0.37*
TGI					0.73**	-0.48**	0.26 NS
GLI						-0.42**	0.37*
RI							-0.39**
	Dry season						
NGRDI		0.90**	0.96**	0.80**	0.90**	-0.47**	-0.28 NS
EXG			0.86**	0.90**	1**	-0.58**	-0.20 NS
SAVI				0.80**	0.86**	-0.54**	0.31*
TGI					0.89**	-0.49**	-0.34*
GLI						-0.57**	0.19 NS
RI							0.15 NS

** Significant at 1%. * Significant at 5% by t-test. NS = not significant; NGRDI = normalized green and red difference vegetation index; EXG = Excess Green Index; SAVI = soil-adjusted vegetation index; TGI = green triangular index; GLI = Leaf Green Index; RI = redness index and PROD = productivity.

It can be observed that the SAVI index is the best vegetative index parameter correlated with productivity in both seasons and can be used as an indicator in the maize crop, using biostimulant products and their application in the proper phenological stages, both in the rainy and the dry season.

4. Discussion

The use of unmanned aerial vehicles (UAV) is a hot topic among renowned researchers focused on cost reduction in plant monitoring, given its labor cost reduction in agriculture, with quick estimates and few hours of flights, obtaining accurate aboveground biomass data (Abrantes, 2019). Several works are using UAVs to estimate biomass in different crops, such as sunflower (Vega et al., 2015), wheat (Lu et al., 2019) and maize (Han et al. 2019). As presented in our study, this tool can estimate vegetative indexes with significant effects.

The indexes studied in the present work are based on the visible spectrum (RGB – RED, GREEN, and BLUE) that can be used for specific purposes and applications (Abrantes, 2019). It is worth mentioning that these indexes of RGB images can be manipulated independently of the architecture of the target plants, describing only the properties of the visible spectra and that are dependent on the reflectance of pigments from the surface of the photographed canopy (Rigon et al., 2016).

The superiority of PE at different doses in the studied index (Table 6) occurred for the two reasons. The NGRDI and ExG indexes had highly significant correlations (above 0.92) with chlorophyll and nitrogen, highlighting their spectral responses in the green and red regions, being more accurate than the indexes using the blue bands, resulting in a high correlation with the physiological parameters (Mendoza-Tafolla et al., 2021), which can infer that the application of PE directly influenced these factors, managing to capture the differences between the colors.

Second, PE has interesting functions and properties to be used in agriculture. Among these, EP can work as a plant biostimulant, compost, rooting inducer, insect repellent, liquid fertilizer, added in organic fertilizers, efficiency enhancer of phytosanitary products, and even improves the physical, chemical, and biological properties of the soil, among other functions (Yahayu et al., 2017). PE also has anti-oxidant and antimicrobial activity that can activate plant defenses, in addition to its use as insecticide, seed germination, and growth promoter plants (Grewal et al., 2018).

The superiority of the HP in the SAVI, TGI, GLI, and RI at different doses may be related to its chemical composition, which contains indolebutyric acid (0.005%), kinetin (0.009%), gibberellic acid (0.005%) and small quantities of chelated mineral salts (Stoller, 2022). These compounds are responsible for cell differentiation, division, and elongation, positively affecting plant growth (Buchelt et al., 2019). This product has been extensively researched in harsh environments, as its use reduces the effects of stress, whether biotic or abiotic (Bontempo et al., 2016).

For AE, the results might be related to its composition (Table 2), which includes amino acids, macro and micronutrients, plant hormones, polysaccharides, and other carbohydrates (Silva et al., 2022). This product reduces the negative effects caused by harsh conditions, improving root yield, grain quality, and productivity. In this sense, AEs have several functions in the plant, such as improved cytokinin activity (increase in cell division), auxin activity (stem growth), gibberellin activity (elasticity and plasticity of cells), batains (reduction of water stress and rupture), and mannitol (chelating agent) (Galindo et al., 2019). EA is a natural source of cytokinins, which promote cell division, delay plant senescence, and influence photosynthetic rates.

The study of the graphic behavior is very important because it provides information on plant performance as the treatment doses increases, both regarding the product (Figure 2 and 3) and the phenological stages (Figure 4 and. 5). Niu et al. (2019) used UAV-based RGB image resources to estimate aboveground biomass and obtained linear increments for all variables studied. The same happened in another experiment where they estimated the biomass of cultivated red algae Pyropia using multispectral imaging based on an unmanned aerial platform, in which their plant indexes showed an increasing linear behavior (Che et al., 2021).

The decreasing linear behavior in the dry season is probably due to the low precipitation (190.4 mm) during the entire cycle (Figure 1B). This amount is insufficient to meet the crop requirements since the ideal amount of water for the maize crop during its cycle is approximately 600 mm (Magalhães and Durães, 2008). This value does not reach 1/3 of the need required by the crop, promoting an accentuated water stress. Even the application of biostimulants was not enough to mitigate the damage caused by the water deficit stress. The same occurred in the rainy season. Although the precipitation level was ideal (646.6 mm), it had no positive effect due to uneven distribution throughout the season, where no precipitation occurred in intervals of 7 days or more.

The indexes that responded to water stress and showed increasing linear or quadratic behaviors with concavities upwards were probably due to the application of HP. This product is composed of the plant hormones cytokinin, indolebutyric acid, and gibberellic acid (Stoller, 2022). In the rainy season, the effects of the application of pH may not be easy to identify because the environmental conditions are favorable for the crop. However, these effects can be clearly noticed when there is stress due to its mitigation (Briglia et al., 2019).

In addition to its effect on plant indexes in different doses, the PE also influences the plant response according to the phenological stage in which it is used. This can be seen in Table 6 and 7, and Figure 6, where it is possible to infer, both in the dry and the rainy season, that the V8 phenological stage stood out with the application of biostimulants. This phenological stage is characterized by having 8 open leaves between 30 and 35 days after emergence (Borém et al., 2017), which corresponds to the definition of the ear size and the number of rows of grains per ear (Magalhães and Durães, 2008).

The superiority of the hormonal product and the high productivity promoted by this product can be attributed to its composition, which contains: 1) auxins – which have promotes cell elongation and stem growth, inhibiting the falling leaves and fruits; it also acts on the differentiation of vascular tissue and on the cell division of cambial tissue, improves the absorption of photoassimilates, promotes greater growth of the flower organs and controls abscission; 2) cytokinins – which promote cell division and differentiation and bud sprouting, expand leaves and cotyledons, delay senescence and decrease the presence of free radicals, increase the synthesis of chlorophyll and the rubisco enzyme, stimulate the opening of stomata, and interfere with photosynthesis, increasing its intensity and consequently productivity; and 3) gibberellins – which promote stem growth, favor seed germination, promote fruit fixation and growth, act on cell division and elongation and delay chlorophyll degradation (Taiz et al., 2017).

The productivity obtained under application with this product was lower than the national average (4890 $kg.ha^{-1}$) but higher than the average productivity in the Northeast region (2554 $kg.ha^{-1}$) and those obtained in the state of Paraíba (780 $kg.ha^{-1}$). This may be attributed to the use of the hormonal product based on auxins, cytokinins, and gibberellins. The ideal dose of this bioregulator product can influence crop productivity (Dourado Neto et al., 2014).

The use of pyroligneous extract has been widely researched in several crops to increase productivity. Almeida Júnior et al. (2022) used pyroligneous extract in maize in southwest Goiás and obtained a 24% increase in productivity (9.160 kg ha^{-1}) with 1L/100 L of H_2O. Similarly, Ofoe et al. (2022) evaluated the influence of pyroligneous extract sprayings on the growth of tomato plants and obtained a significant increase in productivity and quality nutritional of fruits.

The Alga extract only promoted an increase in productivity (Figure 7) in the dry season. This can be explained by its composition (Table 2), which contains carbohydrates, macros and micronutrients, amino acids, vitamins, proteins, and plant hormones that promote several benefits to plants under water stress (Galindo et al., 2019). These same authors showed that the use of the extract of *Ascophyllum nodosum* (200 ml/ha), associated with consecutive sprayings at V4 and V8 (250 ml/ha in each phenological stage), promoted an average of an additional 12 sc/ha compared to no application of this treatment. Silva et al. (2022) applied this product in maize plants at V4 and V8 and obtained a productivity of 7257.36 kg ha^{-1} (12% increase compared to the control) in the 2016 harvest.

The best productivities were achieved, both in the rainy and dry seasons, when plants were treated at V8 (Table 8). The application of plant biostimulants in maize allowed the productivity increment and additionally influences the levels of nutrients important for maintaining the plant's physiological processes (Lima et al., 2020). The same author emphasizes that a high yield can be obtained in maize by applying the products at the correct phenological stage. The V8-R stage, according to Borém et al. (2017) defines the number of grains per row and, consequently, the grain yield. Thus, applying biostimulant products at this stage ensures high grain productivity by mitigating possible biotic and abiotic stress, which corroborates the present results of this research and can be seen in Figure 8, where treatments applied at V8 in the dry season promoted the highest productivity.

SAVI was the vegetative index most significantly influenced by the treatments for both the rainy and dry seasons (Table 9). This is one of the most used indexes in the literature, as it is adjusted to the soil and for measuring the plant's response to red and near-infrared radiation. The SAVI has good performance, can be assessed in areas with low vegetation cover, and is more sensitive to variations in soil type (Menezes and Almeida, 2012). Identifying the best index for the productivity variable is very important, and it can be achieved through Pearson's correlation. This is because Pearson's correlation measures bivariate association (strength) of the degree of relationship between two variables. Even if the Pearson correlation (r) is moderate, eg. between 0.4 and 0.6, it means a positive correlation. In this sense, understanding what the Pearson correlation means and its interpretation is the key to using this parameter in academic studies and with more confidence among the variables evaluated (Figueiredo Filho and Silva Júnior, 2009).

5. Conclusions

Overall, the PE and HP products were the best for both the rainy and dry seasons. However, PH was the best product to mitigate plant water stress, in the dry season, under the conditions of this experiment.

According to the plant indexes, in the rainy season, the best phenological stages for the application of the products are the seed and V8. The best productivities were achieved when treatments were applied at V3 and V8, in the dry season. Therefore, the application at V8 is recommended, considering the plant's performance in the two seasons, the vegetative indexes, and productivity.

The use of Pyroligneous Extract is recommended in the rainy season, and the hormonal product can be used in both seasons.

Levels 3 and 4 (doses of 15.9 and 21.2 L ha^{-1}) of the pyroligneous extract are recommended in the rainy season.

The hormonal product showed many variations, but for productivity, the dose of 600 mL ha^{-1} (level 4) is recommended to be used in the rainy season, and 510 mL ha^{-1} (level 3.4) in the dry season.

The SAVI index was the most suitable parameter to infer better maize crop yields for both studied seasons.

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