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ARTICLE

Humic acid in the production of ornamental lawn plugs and shading levels in the development of Carpet grass

Ácido húmico na produção de plugues de gramas ornamentais e níveis de sombreamento no desenvolvimento da grama São Carlos

Beatriz Watanabe[1], Armando Reis Tavares[2], João Victor Costa[3], Matheus Vinicios Leal do Nascimento[3], Alessandro Reinaldo Zabotto[3], Leandro José Grava de Godoy[4], Roberto Lyra Villas Bôas[3], and Patrick Luan Ferreira dos Santos[3]

[1] Texas A&M University, College Station-TX, United States.
[2] Instituto Agronômico, Jundiaí-SP, Brasil.
[3] Universidade Estadual Paulista (UNESP), Faculdade de Ciências Agronômicas, Botucatu-SP, Brasil.
[4] Universidade Estadual Paulista (UNESP), Faculdade de Ciências Agrárias do Vale do Vale do Ribeira, Universidade Estadual Paulista (UNESP), Registro-SP, Brasil.

Abstract: The use of biostimulants has been studied as a technology that improves the cultivation of plant species and could therefore be an option for producing turfgrass seedlings. Furthermore, Carpet grass is recommended for semi-shaded locations, however there are few studies that indicate the best shading percentage for the species. Thus, this work aimed to evaluate humic acid in the production of ornamental lawns plugs and shading levels in the development of Carpet grass. The experiment was divided into two parts, the first being the production of seedlings (30 days) of Emerald grass, Discovery™ Bermudagrass, Carpet grass and Bahiagrass with application of humic acid. On the second part the development of Carpet grass was evaluated at 4 levels of luminosity (full sun and shading of 30%, 50%, and 80%) in 28 days. The evaluations carried out were: green color index (GCI), normalized difference vegetation index (NDVI), root length and dry mass of the seedlings for the first part. And for the second part: GCI, SPAD (Soil Plant Analysis Development), NDVI, visual aspect, coverage rate, lawn height and dry mass of clippings. It was observed that the use of a humic acid-based biostimulant is recommended in the production of plugs for ornamental lawns, and the best results on Carpet grass, where, the shading level up to 50% for this species is recommended in analyses of up to 28 days.
Keywords: *Axonopus* spp., biostimulant, luminosity, seedling production, turfgrasses.

Resumo: O uso de bioestimulantes vem sendo estudado como uma tecnologia que melhora o cultivo das espécies vegetais, podendo assim ser opção para produção de mudas de grama. Ainda, a grama São Carlos é recomendada para locais semi-sombreados, entretanto são poucos estudos que indicam a melhor porcentagem de sombreamento da espécie. Assim, esse estudo teve como objetivo avaliar ácido húmico na produção de plugs de gramas ornamentais e níveis de sombreamento no desenvolvimento da grama São Carlos. O experimento foi dividido em duas partes, sendo a primeira a produção de mudas (30 dias) de grama Esmeralda, Bermuda Discovery™, São Carlos e Batatais com aplicação de ácido húmico, na segunda parte foi avaliado o desenvolvimento da grama São Carlos em 4 níveis de luminosidade (pleno sol, sombreamento de 30%, 50% e 80%) em 28 dias. As avaliações realizadas foram: índice de cor verde (ICV), índice de vegetação por diferença normalizada (NDVI), comprimento da raiz e massa seca das mudas para a primeira parte. No segundo estudo: ICV, SPAD (Soil Plant Analysis Development), NDVI, aspecto visual, taxa de cobertura, altura do gramado e massa seca das aparas. Observou-se que O uso de bioestimulante a base de ácido húmico é recomendada na produção de plugs de gramados ornamentais, com destaque para a grama São Carlos, onde, o nível de sombreamento até 50% para essa espécie é recomendado em análises de até 28 dias.
Palavras-chave: *Axonopus* spp., bioestimulante, gramados, luminosidade, produção de mudas.

Introduction

During the last few years, ornamental lawns have gained prominence worldwide, primarily due to their admirable aesthetic value (Oliveira et al., 2018; Santos et al., 2020), where visual aspects such as intense green color and density (closed grass, no flaws) are crucial for species acceptance and choice of implantation (Castilho et al., 2020; Villas Bôas et al., 2020). However, when installing ornamental lawns using plugs, it is essential that the seedling is of excellent quality to ensure optimal plant development (Godoy et al., 2012; Oliveira et al., 2018). One of the current market challenges is the search for alternatives to increase production through new technologies, such as the use of biostimulants. Humic acids (HA) are considered an excellent option for their application in turfgrasses (Santos et al., 2019; Tavares et al., 2020; Santos et al., 2024). It is possible to improve nutrient efficiency, increase stress tolerance, and enhance crop quality through the beneficial effects of humic substances (Canellas et al., 2015). According to Baldotto and Baldotto (2014), these substances can represent significant technological opportunities for tropical agriculture.

The turfgrasses used in Brazil are warm-adapted (C4 photosynthetic cycle plants), requiring intense sunlight for their development, which limits their use in shaded areas (Castilho et al., 2020). According to Xie et al. (2020), turfgrasses vary in their light requirements, typically needing full sunlight to achieve maximum light saturation, and they are less tolerant to shading, with the ideal “daily light integral” (DLI) ranging between 6.3 and 20.2 mol m^{-2} d^{-1}, depending on the season (Zhang et al., 2017). However, certain cultivars have demonstrated varying levels of shade tolerance, maintaining acceptable growth and quality even under suboptimal light conditions. Castilho et al. (2020) recommend using species tolerant to semi-shaded areas for landscaping, with Carpet grass (*Axonopus* spp.) being a prominent native Brazilian species (Melero et al., 2020). Carpet grass can be used in landscape projects in semi-shaded areas (Alves, 2019). As observed by Maciel et al. (2011), Carpet grass shows a positive response to 50% shading, performing better compared to Emerald grass (*Zoysia japonica*) and Bermudagrass (*Cynodon* spp.) under similar light conditions.

This species of turfgrass (Carpet grass) is extensively used in landscaping, roadsides, parks, and gardens due to its stoloniferous

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growth. However, it does not offer much resistance to trampling and is more tolerant to milder climates, making it the most cultivated sod in southern Brazil (Godoy et al., 2012; Villas Bôas et al., 2020). Nevertheless, studies concerning the optimal shading levels for this species are still in their early stages, highlighting the need for further research to address this gap (Amaral et al., 2019; Alves, 2019). The objective of the study was to evaluate the influence of humic acid on the production of ornamental lawn plugs and to assess the development of Carpet grass under varying light intensities.

Materials and Methods

The experiment was conducted in a subtropical climate region of the State of São Paulo, and the local climate, according to the Köppen classification, is identified as Aw, with temperatures: average minimum of 17.24 °C, average of 21.34 °C and average maximum of 26.51 °C, with an average relative humidity of 70% per year and annual accumulated precipitation of approximately 1,500 mm (22°53′09″ latitude, 48°26′42″ longitude) (Franco et al., 2023).

The experiment was divided into two stages: the first stage evaluated the influence of Humic Acid (HA) in the production of ornamental lawn plugs, while the second stage assessed the effects of different shading levels on the development of Carpet grass. Four species of turfgrass were used in the first stage: Emerald grass (*Zoysia japonica*), Bermudagrass Discvery™ (*Cynodon dactylon*), Carpet grass (*Axonopus fissifolius*), and Bahiagrass (*Paspalum notatum*).

The first part of the experiment took place in a greenhouse, starting in September 2020, where plugs of different turf species were initially produced using and not using a humic acid biostimulant (11.4 L ha^{-1} Hidra humic®). Vegetative parts (rhizomes and/or stolons) of the four turf species were planted in polyethylene plastic trays (128 cells) filled with commercial substrate (see Table 1). In treatments that received the biostimulant, the dose applied was 10 mL of humic acid in each planting cell. This formed an experimental design in a 4 x 2 factorial scheme (species of turfgrass x use or non-use of the biostimulant) with 10 repetitions (10 plugs per repetition).

Table 1. Characterization of the substrate used in the experiment.

N	P_2O_5	K_2O	Ca	Mg	S	humidity	O.M.	O.C.	Na	Cu	Fe	Mn	Zn	C/N	pH
--------------------- % (natural) ---------------------								dry	----mg kg^{-1} natural --					-----	natural
0.79	0.4	0.15	1.14	2.55	0.15	8	59	36	1369	24	9133	138	44	42/1	5.8

Substrate composed of: Sphagnum peat, expanded vermiculite, roasted rice husk and macro and micronutrients.

Once a day, in the mornings, the treatments were irrigated until the substrates were saturated. Evaluations were conducted after 30 days, assessing the following parameters: Green Color Index (CGI) using the Field Scout CM-1000 Chlorophyll Meter, Normalized Difference Vegetation Index (NDVI), root length, and plug dry mass.

The second part of the experiment was conducted in the field, beginning in October 2020. Plugs of Carpet grass were initially produced in a tray and transplanted into 5 L pots after 30 days, with one plug per pot. The pots were filled with Dystrophic Red Oxisol. Thirty days before setting up the experiment, the soil used was sent to the laboratory for chemical analysis (see Table 2). The soil was amended to achieve a base saturation (V%) of 70%, as recommended for turfgrass establishment by Godoy et al. (2012). Additionally, KCl was added to increase the potassium content to 3 $mmol_c$ dm^{-3}, and a commercial product (inorganic source) was applied to enhance the phosphorus (P_2O_5) and other nutrients levels (16%; 16%; 6.5%; 6.0%; 0.1%; 0.05%; 9.0% and 0.55% corresponding respectively to P, Ca, Mg, S, B, Cu, Mn and Zn).

Table 2. Chemical analysis of soil in the experimental area.

pH	O.M.	P_{resin}	Al^{3+}	H+Al	K	Ca	Mg	SB	CEC	V
$CaCl_2$	g dm^{-3}	mg dm^{-3}	------------mmol$_c$ dm^{-3}---------------							%
4.3	176	4	4	30	0.4	53	1	6	36	16

The site was irrigated using surface drip irrigation, with daily watering adjusted based on the evapotranspiration rate from the previous day. In April 2021, the experiment was initiated after the lawn had fully established and reached the recommended height of 3 cm as advised by Godoy et al. (2012).

There were four levels of luminosity (full sun and shading at 30%, 50%, and 80%), where treatments (except the control) were maintained under shading screens covering all the pots. Thus, the experimental design adopted was a completely randomized design with four shading levels and four replicates per treatment.

The experiment was conducted for 28 days during autumn (April 5th to May 3rd, 2021), with each shading level experiencing varying light intensities throughout the period. Each day, the average luminosity of each treatment was measured using a portable lux meter and converted the values to Photosynthetic Photon Flux Density (PPFD) according to the methodology of Thimijan and Heins (1983) (Table 3).

Table 3. Evaluation of PPFD during the experiment, at different brightness levels.

Shading levels (%)	PPFD (μmol m^{-2} s^{-1})
0	347.13
30	285.70
50	197.35
80	91.09

PPFD: Photosynthetic Photon Flux Density

Assessments were conducted every 7 days throughout the 28-day experiment, evaluating the parameters: Green Color Index (GCI) using the Field Scout CM-1000 Chlorophyll Meter portable meter; SPAD Index using the portable Chlorophyll Meter model SPAD-502 (Soil and Plant Analysis Development); Normalized Difference Vegetation Index (NDVI) estimated using the portable GreenSeeer device to assess the vigor and density of the lawn.

Visual aspect assessed through photographs taken with a 12 Mp camera fixed in a structure called a "light box," similar to that described by Peterson et al. (2011), to standardize lighting conditions.

After 28 days, biometric assessments were conducted, including: Green coverage rate, assessed using photographs taken with the "light box" setup mentioned earlier, with analysis performed using Canopeo® software; Dark Green Color Index (DGCI): Evaluated according to the method by Karcher and Richardson (2003), analyzed using digital images; Leaf length of the lawn was measured using a graduated ruler. The dry mass of clippings was carried out after mowing the lawn to a height of 3 cm, samples were dried in an oven at 60 °C for 72 hours.

Subsequently, the results were analyzed using Tukey's test for variance at a significance level of 5%, employing the statistical software "Statistix 10" for data comparison and interpretation.

Results and discussion

Influence of Humic Acid (HA) in the production of ornamental lawn plugs

Based on the results of the study (Table 4), significant differences were observed between treatments. Specifically, the Green Color Index (GCI) varied significantly between species. Carpet grass exhibited the highest GCI values, differing from all other treatments on average. This result can be attributed to the wider leaves of Carpet grass, which typically contain higher concentrations of chlorophyll (Godoy et al., 2012). According to Santos et al. (2020), chlorophyll content directly influences the green coloration of lawns, and GCI values are directly correlated with chlorophyll levels (Godoy et al., 2012; Santos et al., 2022). In contrast, Discovery™ Bermudagrass and Emerald grass presented the lowest average GCI results. This may be due to their finer leaf structure than the other species examined (Godoy et al., 2012).

Table 4. Averages of GCI, NDVI, root length, and dry mass of seedlings in different turf species with or without the application of humic acid (HA).

Species	GCI			NDVI			Root length			Dry mass		
	Scout CM1000			———			— cm —			— g plug^{-1}—		
	————————— Humic acid —————————											
	with	without	Aver.	with	without	Aver.	with	without	Aver.	with	without	Aver.
Emerald grass	76	63	69 c	0.19 bA	0.13 bA	0.16 c	5.5	5.9	5.7 ab	0.42	0.29	0.35 b
Carpet grass	107	95	101 a	0.43 aA	0.33 aB	0.38 a	5.1	5.5	5.3 b	0.68	0.68	0.68 b
Bahiagrass	92	83	88 b	0.27 bA	0.33 aA	0.30 b	5.6	5.2	5.4 b	1.35	1.26	1.30 a
Discovery™ Bermudagrass	70	68	69 c	0.22 bA	0.19 bA	0.21 c	6.1	6.0	6.0 a	0.54	0.63	0.58 b
Average	86 A	77 B	--	0,28	0.29	--	5.5	5.6	--	0.71	0.75	--
$F_{Species}$	64.643**			39.519**			4.621*			18.681**		
F_{HA}	21.909**			4.23^{ns}			0.218^{ns}			0.134^{ns}		
$F_{Species\ x\ HA}$	1.918^{ns}			4.490*			1.685^{ns}			0.265^{ns}		
CV (%)	6.71			16.70			8.14			36.48		

Averages followed by the same lowercase letter in the column and uppercase in the row, do not differ from each other, by Tukey's test at a level of 5%. ** - significant at 1%, * - significant at 5%, ns - not significant. Aver. – Average.

Regarding the use of humic acid to evaluate the GCI, it is noted that despite there being no interaction between the factors, the average of the treatments showed a difference. Humic acid improves turf quality and physiological growth, requiring smaller amounts of mineral fertilizers (Zhang et al., 2003). Aalipour et al. (2020) observed a higher nitrogen concentration with the use of HA in two species of winter turfgrasses and, consequently, an increase in the green color of the species. Zhang et al. (2020) observed positive responses in chlorophyll content after the application of humic acid in Bentgrass (*Agrostis* spp.). This effect is probably due to the ability of HA to increase the production of plant hormones crucial for turfgrass growth, such as cytokinins and indole acetic acid (Zhang and Ervin, 2004; Zhang et al., 2020). Similar observations were observed in the present study.

The NDVI is an important parameter for calculating the fraction of green vegetation on the soil surface, as it correlates with leaf area and the nutritional status of plants (Santos et al., 2024). In our study, we observed a notable response from Carpet grass when treated with biostimulant. NDVI values close to 1 indicate denser and more biomass-rich turfgrass (Nascimento et al., 2020). However, these values can vary among turfgrass species (Silva et al., 2020; Nascimento et al., 2020) and depend on whether the turfgrass is fully established. In our study, the observed NDVI values were relatively low, reflecting the fact that the lawns were still in the seedling phase and not fully established. Despite this, Carpet grass exhibited a higher NDVI, which can be attributed to its broader leaves compared to other species (Melero et al., 2020; Castilho et al., 2020).

In terms of root length and dry mass, no statistically significant difference was observed with the application of the biostimulant in our study; the differences were only notable between different turfgrass species. Bahiagrass, in particular, exhibited superior dry mass results, possibly due to its superficial rhizomes that accumulate significant reserves and contribute to increased mass (Lima et al., 2020). Contrary to the findings of Zhang et al. (2020), who reported enhanced root growth in turfgrass following biostimulant application, our results did not show such effects within the 30-day period of our study. This suggests that the efficacy of humic acid as a biostimulant may vary among turfgrass species, and longer observation periods might be necessary to fully assess its impact on root development.

Effects of different shading levels on the development of Carpet grass

The SPAD index, in the second stage of the experiment, revealed statistically significant differences starting from 14 days after the experiment's initiation (Table 5). The lack of significant differences at 7 days could be attributed to insufficient shading duration to influence results effectively. Throughout the subsequent evaluation days, plants cultivated in shading levels between 50% and 80% consistently showed higher SPAD index values compared to those in full sun (0%). This response is likely due to lower light intensity prompting plants to produce higher chlorophyll content to maintain metabolic functions (Taiz et al., 2017). This phenomenon was clearly reflected in the SPAD index values observed in our study.

Carpet grass is widely recommended for semi-shaded areas (Dias et al., 2018), highlighting the importance of determining the optimal shading levels it can tolerate. While shading levels of 80% showed the highest SPAD index values in our study, this does not necessarily indicate that it is the ideal shading level. High shading levels can lead to increased chlorophyll production, but at the expense of depleting metabolic reserves needed for overall vegetative growth (Godoy et al., 2012). Currently, there is no established ideal SPAD index value specifically for Carpet grass in the literature. Therefore, the results of our study contribute valuable information to fill this gap and improve understanding of how Carpet grass responds to different shading conditions. This knowledge is crucial for optimizing the cultivation and management of Carpet grass in landscaping and other applications where light conditions vary.

Table 5. The SPAD index during the execution of the experiment

Shading levels (%)	Days after experiment installation (Days)			
	7	14	21	28
	---------------------------- SPAD -------------------------------			
0	29.2	30.6 B	29.2 C	26.3 C
30	33.6	36.4 AB	34.4 B	35.2 B
50	35.0	34.9 AB	35.8 AB	38.4 AB
80	36.4	41.1 A	38.3 A	43.2 A
MSD	8.7	9.8	3.5	5.6
F	2.29^{ns}	3.43*	20.69**	28.36**
CV (%)	12.3	13.06	4.91	7.45

Averages followed by the same letter in the column do not differ from each other, by Tukey's test at 5% level. ** - significant at 1%, * - significant at 5%, ns - not significant. MSD - Minimum Significant Difference

Similar to the results observed for the SPAD index values (Table 5), the Green Color Index (GCI) measured with the Scout CM1000 showed that 80% shading maintained the highest levels of green color (Table 6). However, unlike the SPAD index, differences in GCI were evident as early as 7 days after treatment initiation. As mentioned earlier, lower light intensity stimulates greater production of leaf chlorophyll, and this effect becomes more pronounced over time. This phenomenon likely explains the consistent increase in green color observed under higher shading levels throughout the duration of the study.

The leaf chlorophyll index assessed with the SCOUT CM1000 portable device is highly accurate for estimating the nutritional status of plants (Godoy et al., 2012). In our study, higher Green Color Index (GCI) values indicate higher concentrations of foliar nitrogen (N), as chlorophyll molecules are magnesium porphyrins composed of a central magnesium atom linked to four nitrogen atoms (Taiz et al., 2017). Despite the stress induced by varying light intensities in our treatments, the results demonstrate that the species studied are capable of maintaining acceptable levels of chlorophyll and, consequently, green coloration even under suboptimal light conditions. This resilience underscores the adaptability of these turfgrass species to fluctuating environmental conditions, which is crucial for their performance in diverse landscaping and agricultural settings.

Table 6. SCOUT CM1000 green color index during the execution of the experiment

Shading levels (%)	Days after experiment installation (Days)			
	7	14	21	28
	---------------------- SCOUT CM1000 -----------------------			
0	143 B	137 C	152 C	161 C
30	173 AB	175 B	178 BC	202 BC
50	202 A	194 B	211 B	234 B
80	171 AB	248 A	280 A	291 A
MSD	54	19	33	46
F	3,46*	105.17**	49.20**	24.81**
CV (%)	15.07	4.77	7.7	9.98

Averages followed by the same letter in the column do not differ from each other, by Tukey's test at 5% level. ** - significant at 1%, * - significant at 5%, ns - not significant. MSD - Minimum Significant Difference

The most significant NDVI results emerged after 21 days of experiment implantation, with the highest values observed between shading levels of 50% to 80%. By the end of the 28-day period, the 80% shading level exhibited the highest NDVI values (Table 7). The NDVI index is closely linked to the leaf area and nutritional status of plants (Santos et al., 2024). A value closer to 1 indicates greater plant biomass and vigor, which is particularly important for turfgrass health (Nascimento et al., 2020). However, while the results at 80% shading showed the highest NDVI values, this does not necessarily indicate that this shading level is optimal. High shading levels can indeed promote greater leaf growth and chlorophyll production, contributing to higher NDVI values. However, excessive shading can also negatively impact other parts of the lawn, such as roots and stolons, which may grow at a slower rate. This imbalance can make the turfgrass more susceptible to pests and diseases (Pagliarini et al., 2021). Therefore, while high NDVI values indicate vigorous growth, achieving a balance in shading levels is crucial to maintain overall turfgrass health and resilience.

Table 7. Normalized Difference Vegetation Index (NDVI) during the execution of the experiment.

Shading levels (%)	Days after experiment installation (Days)			
	7	14	21	28
	---------------------------- NDVI ---------------------------			
0	0.39	0.51	0.33 C	0.35 D
30	0.49	0.53	0.49 B	0.51 C
50	0.48	0.56	0.58 A	0.62 B
80	0.45	0.56	0.64 A	0.73 A
MSD	0,17	0,21	0.09	0.08
F	1.2^{ns}	0.23^{ns}	44.15**	67.46**
CV (%)	18.4	18.36	8.04	7.21

Averages followed by the same letter in the column do not differ from each other, by Tukey's test at 5% level. ** - significant at 1%, * - significant at 5%, ns - not significant. MSD - Minimum Significant Difference

After 28 days of implantation, various parameters including the Green Color Index, Green Cover Rate, turfgrass height, and dry mass of clippings were analyzed (Table 8). Overall, shading levels of 50% and 80% consistently showed higher values compared to other treatments. However, it's important to consider the implications of very intense growth in turfgrass height and the accumulation of dry mass, particularly observed under 80% shading. While these conditions may lead to vigorous foliar development and higher biomass production, they also pose challenges. Firstly, such rapid growth requires significant utilization of plant reserves, which could impact overall lawn health and resilience over time. Additionally, maintaining a lawn with excessive growth height necessitates more frequent mowing to uphold quality standards, resulting in increased operational costs (Mateus et al., 2020; Santos et al., 2022).

Lawns subjected to shading often respond by increasing their growth to compensate for reduced light availability, which can lead to disproportionate development and potential harm to other vegetative parts (Pagliarini et al., 2021). In our study, we observed a significant increase in plant biomass under high shading levels, indicating that shading up to 30% can be a practical option for cultivating Carpet grass without compromising its aesthetic appeal and overall development. Specifically, the results obtained at 50% shading align closely with findings reported by Dias et al. (2018) for Carpet grass grown in soil after the initial mowing, where a biomass of 147.85 g m^{-2} was observed. This suggests that moderate shading levels around 30% to 50% can sustain adequate grass growth within acceptable standards.

The results obtained for Dark Green Color Index (DGCI) values ranging from 0% to 50% shading in our study align with findings reported by Melero et al. (2020), who observed DGCI values between 0.31 and 0.53 under similar conditions. This consistency supports the notion that 80% shading leads to an increase in leaf chlorophyll content, as indicated by higher DGCI values. However, it is crucial to emphasize the importance of lawn aesthetics, particularly for ornamental lawns. Ornamental lawns must maintain high aesthetic quality characterized by a vibrant green color, dense growth, and a flawless appearance to uphold sensory quality (Prates et al., 2020). In contrast, lawns in residential or industrial settings often maintain lower to moderate quality levels, contingent upon the care provided by their owners (Castilho et al., 2020). Excessive growth, particularly under intense shading conditions, can compromise the maintenance and aesthetic appeal of turfgrass species. Images depicted in Figure 1 illustrate that Carpet grass subjected to shading up to 50% managed to maintain its aesthetic quality and green cover index over the course of 28 days in our study. Maintaining the visual aspect of lawns, ensuring they are visually appealing, is crucial as highlighted by Melero et al. (2020), which is consistent with the findings observed in our study (Fig. 1). This visual appeal is essential for creating a pleasing landscape environment. Additionally, Lima et al. (2020) observed that using Paclobutrazol resulted in a more compact leaf structure for Bahiagrass. However, this treatment also caused the rhizomes of Bahiagrass to become exposed, which subsequently reduced the green density of the lawn.

Table 8. DCGI, Green Coverage Rate, Height and Dry Mass of the clippings after 28 days of experiment installation

Shading levels (%)	DCGI		Green coverage rate		Height		Dry mass	
	Adm		%		cm		g m^{-2}	
0	**0.36**	**D**	**80.5**	**B**	**4.3**	**D**	**85.7**	**C**
30	0.47	C	84.7	B	6.8	C	119.4	B
50	0.52	B	90.0	A	8.8	B	148.6	A
80	0.59	A	91.3	A	10.7	A	167.3	A
MSD	0.03		5.0		1.6		23.5	
F	168.79**		17.24**		53.0**		40.44**	
CV (%)	3.05		2.76		10.02		8.61	

Averages followed by the same letter in the column do not differ from each other, by Tukey's test at 5% level. ** - significant at 1%, * - significant at 5%, ns - not significant. MSD - Minimum Significant Difference. Adm – Admensional.

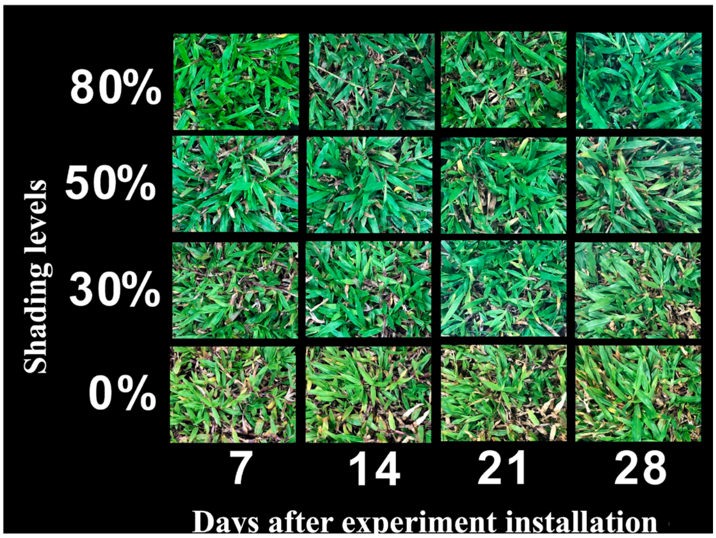

Fig. 1. Development of the lawn in the different levels of shading over the days, in photos taken with the light box

Conclusions

The use of a humic acid-based biostimulant is highly recommended in the production of plugs for ornamental lawns, particularly due to the observed improvements, which were most notable for Carpet grass. Our study showed significant enhancements in growth under shading levels ranging from 50% to 80% over a period of up to 28 days. However, based on our findings, shading levels of around 30% – 50% may be particularly recommended for optimal Carpet grass development, with higher levels being avoided. These moderate shading levels support a higher concentration of green coloration without causing excessive growth or compromising vegetative structures. This balance is crucial for maintaining the aesthetic quality of the lawn while ensuring sustainable growth and resilience.

Therefore, managing shading levels effectively, coupled with the application of biostimulants like humic acids, can enhance the development and visual appeal of ornamental lawns, specifically benefiting species such as Carpet grass in various landscaping and horticultural applications.

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Author Contribution

BW: Conceptualization, Data Curation, Formal Analysis, Investigation, Writing – Original Draft. **ART:** Resources, Writing – Review & Editing, Validation. **JVC**: Investigation, Methodology, Visualization. **MVLN:** Investigation, Methodology, Visualization. **ARZ:** Investigation, Methodology, Visualization. LJGG: Investigation, Methodology, Visualization, Writing – Review & Editing, Funding Acquisition, Resources. **LVB:** Investigation, Methodology, Visualization, Writing – Review & Editing, Funding Acquisition, Project Administration, Resources. **PLFS:** Investigation, Methodology, Visualization, Writing – Review & Editing, Supervision.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All the research data is contained in the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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