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USE OF THE IMAZAPIC HERBICIDE APPLIED ALONE OR TANK MIX WITH IMAZAPYR AS GROWTH REGULATOR OF LAWNS

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Abstract
Successive mowing are the major maintenance costs of lawns. Thus, both the expenditure with mowing and the visual and physiological aspect of the lawn have led to the search for alternatives to mechanical management. Thus, this work aimed to study the effects of different rates of imazapic herbicide applied alone or combined with imazapyr as a growth regulator of Bahiagrass (*Paspalum notatum*) and St. Augustine grass (*Stenotaphrum secundatum*). The experimental design was a randomized block with four replicates, and the treatments consisted of six rates of imazapic herbicide (35; 70; 105; 140; 175 and 210 g a.i. ha^{-1}) for both species, three rates of imazapic + imazapyr in tank mix (15.57 + 5.25; 23.625 + 7.875; 32.5 + 10.5 g a.i. ha^{-1}) for Bahiagrass and four rates of imazapic + imazapyr mixture (7.875 + 2.625; 15.57 + 5.25; 23.625 + 7.875; 32.5 + 10.5 g a.i. ha^{-1}) for St. Augustine grass. The effect of the treatments was evaluated by observing visible injury symptoms, canopy height, height and number of inflorescences and total dry matter of clippings. Applications of imazapic alone or combined with imazapyr were effective in reducing plant height, number and height of inflorescences and total amount of dry matter of clippings produced by Bahiagrass plants. Imazapic provided satisfactory control of St. Augustine growth, but its utilization caused an increase in the number of inflorescences present in the lawns.

Keywords: Imidazolinone. *Paspalum notatum*. Plant inhibitors. *Stenotaphrum secundatum.*

1. Introduction

The grass species Bahiagrass (*Paspalum notatum* Flügge) and St. Augustine (*Stenotaphrum secundatum* (Walter) Kuntze) are some of the main types of turfgrass used in lawns grown in the most diverse environments and for numerous purposes, whether in residential, industrial and public areas as well as in airports, parks, square gardens, roadsides and sports fields, found in countries with equatorial, tropical and subtropical climates (Li et al. 2011; Coan et al. 2012).

One of the main characteristics of Bahiagrass is the formation of a dense lawn due to the interweaving of stolons that penetrate the soil and easily root. However, the visual aspect of lawns with this species can be damaged by the great number of flower stems, which often have shades of color that clash with the color of the grass blades (Gates et al. 2004). In addition, both blades and flower stems may reach excessive heights, requiring constant mowing to maintain plant height uniformity and visual quality of the lawn (Marchi et al. 2016).

St. Augustine grass, in turn, does not require much care when growing but requires medium to highly fertile and well-drained soils and adequate light conditions. However, this species produces a large amount of biomass when it grows under the cited conditions and need to be mowed every week during the growing stage to keep the lawn with a very attractive appearance (Kimball et al. 2017).

Successive mowing are the major sources of lawn maintenance costs, which, together with a large quantity of grass clippings and repetitive activities of raking the clippings into piles and transporting them have become the main factors of rejection to the use of this technique, in addition to the constant removal of nutrients that must be replaced, increasing the costs of this activity even more (Marchi et al. 2014).

Therefore, both the costs of successive mowing and the visual and physiological aspects of the lawn have encouraged the search for alternatives to mechanical management (Mccarty et al. 2011; March et al. 2013). Thus, the use of selective herbicides that have a regulatory effect on plant growth without damaging the visual aspect of the lawn can be a very interesting management tool due to the dual purpose to be achieved (Maciel et al. 2011).

The imazapic herbicide, for instance, is often used to control some grass species and broadleaf weed plants in pre- and post-emergence applications (Rinella et al. 2013; Bajrai et al. 2017). The imazapic + imazapyr formulated mixture is also recommended for the control of weed plants such as sedge (*Cyperus rotundus* L.), little bell (*Ipomoea grandifolia* (Dammer) O'Donell) and wild poinsettia (*Euphorbia heterophylla* L.) (Matte et al. 2018). However, Maciel et al. (2013) report that besides the herbicide action, imazapic can also be selective and viable for use as regulator of grass plant growth and development and can reduce the number of lawns cuttings.

It should be emphasized that tests with herbicides as plant growth regulators are still a recently experimented field of study and lack information to understand the physiological implications that affect the grass aesthetical performance (Velini et al. 2010; Barbosa et al. 2017). Given the above, the present work aims to study the effects of imazapic herbicide applied alone or combined with imazapyr in tank mix as a plant regulator of vegetative growth and inflorescence of Bahiagrass and St. Augustine grass species in field conditions.

2. Material and Methods

The experimental phase of the present research comprised two studies carried out in experimental areas located at the Núcleo de Pesquisas Avançadas em Matologia – NUPAM [Center for Advanced Research on Weed Plants] of the Departamento de Produção Vegetal, [Department of Plant Production] of the Faculdade de Ciências Agronômicas [Faculty of Agronomic Sciences] of Botucatu/UNESP, at the geographic coordinates of 22°07'56''S and 74°66'84''WGr., 762 m of altitude, between November to February.

The climate of the region, according to the classification of Köppen (1948), is of the Cfa type - temperate rainy climate, characterized as having a humid climate with water deficiency in April, July and August and rainy period that is concentrated in the spring-summer months, with an average annual rainfall of 1.517 mm and an average annual temperature of 20.2 ºC. The average temperature of the hottest months is 23.2 ºC and the coldest months are 16.9 ºC. The average precipitation in the rainy months is 223.4 mm and in the drought months it is 37.8 mm (Cunha and Martins 2009).

The lawns, approximately 14 months old, were formed with Bahiagrass and St. Augustine grass mats in areas equipped with a sprinkler irrigation system. The soil was classified as a typical dystropherric Red Nitosol with moderate A horizon and clayey structure (EMBRAPA 2006). After the application of 2.6 tons ha^{-1} of limestone, samples were collected from this soil and sent for analysis in laboratory, and the chemical characteristics of the soil are described in Table 1.

Table 1. Chemical characteristics of the soil at 0-20 cm depth.

pH $CaCl_2$	Org.C./1	P	Ca	Mg	K	Al	Al+H	CEC/2	V/3	Fe_2O_3
(0.01 mol L^{-1})	g kg^{-1}	mg kg^{-1}	----------------			mol_c kg^{-1}		-----------------	%	g kg^{-1}
5.9	15	12	27	13	9.6	0.3	32.9	82.9	60	176

/1 – organic Carbon; /2 – cation exchange capacity; /3 – base saturation.

The treatments described in Table 2 were arranged in a randomized block experimental design with four replicates. Each experimental plot had a total area of 3.75 m^2 (1.5 m x 2.5 m). In addition to the control plot (without herbicides application), a 0.5 m^2 strip along the experimental blocks was kept as a lateral control for a better visualization of injury effects caused by the chemical treatments tested.

Table 2. Application rates of imazapic alone and imazapic + imazapyr in tank mix on Bahiagrass (*Paspalum notatum*) and St. Augustine (*Stenotaphrum secundatum*) grasses.

Bahiagrass	St. Augustine
Treatment + Rate (g a.i. ha^{-1})	Treatment + Rate (g a.i. ha^{-1})
imazapic 35	imazapic 35
imazapic 70	imazapic 70
imazapic 105	imazapic 105
imazapic 140	imazapic 140
imazapic 175	imazapic 175
imazapic 210	imazapic 210
imazapic+imazapyr 15.6+5.2	imazapic+imazapyr 7.9+2.6
imazapic+imazapyr 23.6+7.9	imazapic+imazapyr 15.6+5.2
imazapic+imazapyr 32.5+10.5	imazapic+imazapyr 23.6+7.9
-----------	imazapic+imazapyr 32.5+10.5

The lawns were cut two days before application of the treatments at a height of 3.0 to 5.0 cm above the ground using a motorized mower with rotating blades. The herbicide applications were performed using a CO_2-pressurized backpack sprayer with spraying boom containing two flat jet nozzles (TP 8002VS), spaced 0.50 cm apart, at constant pressure of 200 Kpa and set to deliver 200 L ha^{-1} of the solution. During application, the plots were laterally protected with plastic canvas to avoid possible drifts of the sprayed solution to the adjacent plots.

The effect of the treatments was evaluated weekly by observing visible symptoms of injuries and the height of the lawn canopy. The evaluation performed at 119 DAA (days after application) corresponded to the final period in which the plants, both in the treated and non-treated (control) plots, did not exhibit alterations in height for both grass species. The injuries were evaluated visually using a scale from 0 (total absence of injuries) to 100% (plant death) (SBCPD 1995). The grass height was expressed in centimeters and determined by direct measurement of the plants canopy using a graduated ruler.

The number of inflorescences was determined by sampling using a 0.25 m^2 metal square placed in the center of the plots. The inflorescence height was determined using a graduated ruler, by measuring the distance from the ground and the inflorescence extremity, considering only the highest inflorescence in the center of each plot.

The total dry matter of clippings was determined by collecting the plant mass produced in the plots after cutting the grass at the height of 3 cm from the surface using a powered mower. The samples were placed in paper bags and kept in a forced-air circulation oven at 65 ºC during three days to reach constant weight, when then they were weighted in a 0.01g precision scale.

The values obtained for all variables cited were analyzed by F-test, and the effects of the treatments were compared by Scott-Knott test at the 5% probability level, using the statistical program AgroEstat (Barbosa and Maldonado Jr. 2015).

3. Results

Bahiagrass (*Paspalum notatum*)

Bahiagrass exhibited high sensitivity to imazapic, considering that at 7 DAA, injury levels above 45-47% were observed, even with the lowest application rate of the herbicide (35 g ha^{-1}). The imazapic + imazapyr mixture also caused high levels of injury in the Bahiagrass plants, which exhibited 38% of injury at 7 DAA for the lowest application rates (imazapic+imazapyr 15.6+5.2 and 23.6+7.9 g ha^{-1}) and above 53% when the combined herbicides (imazapic+imazapyr) were applied at the rates of 32.5+10.5 g ha^{-1}, respectively (Table 3).

Table 3. Visible injury provided by imazapic applied alone and in tank mix with imazapyr on Bahiagrass plants (*Paspalum notatum*).

Treatment + Rate (g a.i. ha^{-1})	Injury (%) DAA\1					
	7	14	28	35	56	119
imazapic 35	47.0^{c}	23.2^{e}	22.5^{d}	10.5^{e}	4.0^{e}	4.0^{e}
imazapic 70	45.0^{c}	27.5^{d}	26.2^{d}	28.7^{d}	30.0^{d}	30.0^{d}
imazapic 105	52.5^{b}	33.3^{c}	32.5^{c}	41.2^{c}	50.0^{c}	50.0^{c}
imazapic 140	52.5^{b}	38.7^{b}	38.8^{b}	50.0^{b}	60.0^{b}	60.0^{b}
imazapic 175	62.5^{a}	35.0^{c}	35.0^{c}	52.5^{b}	67.5^{a}	67.5^{a}
imazapic 210	60.0^{a}	46.3^{a}	46.3^{a}	62.5^{a}	73.8^{a}	73.8^{a}
imazapic+imazapyr 15.6+5.2	38.7^{c}	32.0^{c}	18.2^{e}	4.5^{f}	0.0^{e}	0.0^{e}
imazapic+imazapyr 23.6+7.9	39.5^{c}	25.2^{d}	18.8^{e}	6.5^{f}	2.0^{e}	2.0^{e}
imazapic+imazapyr 32.5+10.5	53.8^{b}	20.8^{e}	20.0^{e}	12.5^{e}	6.5^{e}	6.5^{e}
Control	0.0^{d}	0.0^{f}	0.0^{f}	0.0^{f}	0.0^{e}	0.0^{e}
F Treatment	31.76**	63.39**	100.01**	98.21**	127.12**	127.12**
F Block	1.34^{NS}	1.59^{NS}	4.89**	1.89^{NS}	3.72*	3.72*
C.V. (%)	13.91	11.14	10.10	17.30	18.48	18.48

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column do not differ statistically from each other by the Scott-Knott test at 5% probability level. \1 DAA – days after application.

The injury symptoms recorded at 7 DAA for the rates of imazapic applied alone were decline until the evaluation performed at 28 DAA, with values that ranged from 23 and 46% of toxicity for the herbicide doses between 35 and 210 g ha^{-1}, respectively (Table 3).

In the subsequent evaluations (35 and 56 DAA), an increase of the visible symptoms of injury was observed for the herbicide rates above 35 g ha^{-1}, which stayed constant until the evaluation made at 119 DAA, with values higher than 73% for the application rate of 210 g ha^{-1}. Reduced levels of injury were observed only for the lowest rate of imazapic applied (35 g ha^{-1}), which decreased from 22% at 28 DAA to 4% at 56 DAA (Table 3).

After the evaluation performed at 7 DAA, there was an apparent recovery of the Bahiagrass treated with imazapic+imazapyr. Regardless the herbicide rates applied, it could be seen that there was a sharp decrease in the values of visible injury by 56 DAA, considering that the values tended to zero for the 15.6+5.2 g ha^{-1} without symptoms rate and remained constant by 119 DAA for 23.6+7.9 and 32.5+10.5 g ha^{-1} rates with values of 2.0 and 6.5%, respectively (Table 3).

With respect to the average grass height, it was found that the rates of imazapic applied alone that were over 35 g ha^{-1} and mixed with imazapyr at rates of 23.6+7.9 and 32.5+10.5 g ha^{-1} provided a satisfactory control of Bahiagrass growth by 119 DAA (Table 4). All treatments cited did not reach the critical cut limit of 70% of the mean height of the control (untreated plot), which is considered vital when decisions are made on possible reapplications of growth regulators in lawns (Costa et al. 2010).

Table 4. Mean height of Bahiagrass (*Paspalum notatum*) obtained in different times as a result of application of imazapic alone and in tank mix with imazapyr.

Treatment + Rate (g i.a. ha^{-1})	Grass height (cm) DAA\1						
	7	14	28	35	56	119	(%)\2
imazapic 35	7.6^{b}	8.0^{c}	8.9^{b}	9.1^{b}	12.8^{b}	31.5^{b}	30.0
imazapic 70	6.3^{b}	6.7^{d}	8.6^{b}	9.1^{b}	10.9^{c}	28.9^{b}	35.8
imazapic 105	7.2^{b}	7.5^{d}	8.8^{b}	8.7^{b}	9.1^{c}	24.0^{c}	46.7
imazapic 140	6.3^{b}	6.8^{d}	8.7^{b}	9.0^{b}	9.2^{c}	24.7^{c}	45.1
imazapic 175	7.2^{b}	7.3^{d}	6.4^{d}	7.5^{b}	8.6^{c}	19.8^{c}	56.0
imazapic 210	6.7^{b}	7.1^{d}	9.1^{b}	9.3^{b}	9.1^{c}	18.2^{c}	59.6
imazapic+imazapyr 15.6+5.2	9.2^{b}	10.1^{b}	9.1^{b}	10.6^{b}	15.5^{b}	32.7^{b}	27.3
imazapic+imazapyr 23.6+7.9	7.9^{b}	8.1^{c}	9.5^{b}	10.0^{b}	14.7^{b}	30.5^{b}	32.2
imazapic+imazapyr 32.5+10.5	7.3^{b}	7.3^{d}	7.4^{c}	8.5^{b}	11.9^{b}	23.3^{c}	48.2
Control	16.1^{a}	19.1^{a}	20.9^{a}	23.2^{a}	29.0^{a}	45.0^{a}	----
F Treatment	28.48**	163.20**	360.89**	37.60**	29.72**	16.92*	----
F Block	3.48*	1.35^{NS}	1.80^{NS}	3.31*	2.02^{NS}	5.84**	----
C.V. (%)	13.14	6.69	4.35	14.09	17.08	16.91	----

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column do not differ statistically from each other by the Scott-Knott test at 5% probability level. \1 DAA – days after application; \2 – reduction calculated in comparison with the control.

The application of imazapic herbicide alone and its combination with imazapyr also exhibited high efficacy in reducing the variables height and number of seedheads. It can be seen that these variables, in all treatments evaluated in this study, were lower than the control (without herbicide application). For all doses applied, values between 65 and 100 % of reduction in the number of seedheads, compared with the control (non-treated), were found, with emphasis for the rate 32.5+10.5 g ha^{-1} of imazapic combined with imazapyr, which totally inhibited the reproductive development of the Bahiagrass plants by 119 DAA (Table 5).

All treatments also provided a significant reduction in the production of total dry biomass of Bahiagrass clippings when compared with the control. Such reductions ranged from 36.9 to 56.9%, compared with the treatment without herbicides application, and were more intense especially with rates above 70 g ha^{-1} of the imazapic herbicide applied alone. It can be seen that the applications of different rates of imazapic combined with imazapyr caused a reduced production of dry biomass of clippings, similar to the ones found in the control (Table 5).

Table 5. Mean values of height and number of inflorescences and total dry matter of clippings (TDMC) produced by Bahiagrass at 119 days after application of the herbicides.

Treatment + Rate (g i.a. ha^{-1})	Inflorescence			TDMC	
	Height (cm)	Number (m^{-2})	(%)\1	g m^{-2}	(%)\1
imazapic 35	46.0^{b}	16.2^{d}	84.6	469.4^{b}	36.9
imazapic 70	33.8^{c}	13.7^{d}	86.9	387.0^{c}	48.0
imazapic 105	34.3^{c}	7.5^{e}	92.8	336.8^{c}	54.7
imazapic 140	36.2^{c}	10.0^{e}	90.5	355.9^{c}	52.2
imazapic 175	25.0^{d}	6.2^{e}	94.1	339.2^{c}	54.4
imazapic 210	20.9^{d}	17.5^{d}	83.3	320.9^{c}	56.9
imazapic+imazapyr 15.6+5.2	46.2^{b}	36.3^{b}	65.4	443.4^{b}	40.4
imazapic+imazapyr 23.6+7.9	32.2^{c}	27.5^{c}	73.9	439.6^{b}	40.9
imazapic+imazapyr 32.5+10.5	0.0^{e}	0.0^{e}	100.0	414.3^{b}	44.3
Control	61.3^{a}	105.0^{a}	----	743.9^{a}	----
F Treatment	23.17*	117.68**	----	21.72**	----
F Block	3.35*	0.40^{NS}	----	4.25*	----
C.V. (%)	19.18	22.73	----	11.80	----

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column do not differ statistically from each other by Scott-Knott test at 5% probability level. \1 – reduction calculated in comparison with the control.

St. Augustine grass (*Stenotaphrum secundatum*)

All imazapic herbicide rates applied alone caused considerable visible injuries in St. Augustine grass plants at 7 DAA. The lowest injury level observed was 10.5%, resulting from application of the dose of 35 g ha^{-1}. The toxic effect caused by the herbicide was not constant as the rates increased, with toxicity values between 16.3 and 22.8% (Table 6).

The imazapic + imazapyr mixture also caused acceptable injury levels in plants of the *S. secundatum* species, and the values found at 7 DAA were higher than 12.7% and lower than 29% of injury, regardless the rates applied (Table 6).

Table 6. Visible injury provided by imazapic applied alone and in tank mix with imazapyr on St, Augustine plants (*Stenotaphrum secundatum*).

Treatment + Rate (g a.i. ha^{-1})	Injury (%) DAA\1				
	7	14	21	28	30
imazapic 35	10.5^{d}	8.0^{d}	5.0^{b}	1.3^{c}	0.0
imazapic 70	22.7^{b}	20.0^{b}	7.0^{b}	1.5^{c}	0.0
imazapic 105	19.0^{c}	17.0^{c}	6.0^{b}	1.9^{b}	0.0
imazapic 140	20.3^{b}	17.0^{c}	7.0^{b}	1.7^{b}	0.0
imazapic 175	16.3^{c}	15.0^{c}	9.7^{a}	2.1^{a}	0.0
imazapic 210	22.8^{b}	20.0^{b}	10.8^{a}	2.2^{a}	0.0
imazapic+imazapyr 7.9+2.6	12.7^{d}	10.0^{d}	2.0^{c}	1.0^{d}	0.0
imazapic+imazapyr 15.6+5.2	17.5^{c}	15.0^{c}	4.5^{b}	1.0^{d}	0.0
imazapic+imazapyr 23.6+7.9	28.8^{a}	25.0^{a}	5.8^{b}	1.0^{d}	0.0
imazapic+imazapyr 32.5+10.5	17.0^{c}	15.0^{c}	7.8^{b}	1.2^{c}	0.0
Control	0.0^{e}	0.0^{e}	0.0^{c}	0.0	0.0
F Treatment	25.30**	24.18**	16.47**	14.21**	----
F Block	2.17^{NS}	1.13^{NS}	1.61^{NS}	2.42^{NS}	----
C.V. (%)	15.59	18.65	25.77	16.74	----

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column do not differ statistically from each other by Scott-Knott test at 5% probability level. \1 DAA – days after application.

After the evaluation at 7 DAA, there was a gradual recovery of St. Augustine grass plants treated either with imazapic applied alone or combined with imazapyr, considering that the visible injury symptoms for all treatments at 28 DAA were between 1.0 and 2.2%. At 30 DAA, there was a total recovery of the St. Augustine lawns for all treatments applied in this experiment, and no injury symptom was found in this period (Table 6).

The vertical vegetative growth of St. Augustine plants was significantly affected by all rates of imazapic applied alone or in combination with imazapyr, from 7 DAA, compared with the control (Table 7). It should also be noted that except for the rate of 105 g ha^{-1} of imazapic alone, all treatments of this experiment provided an acceptable growth control of the grass by 119 DAA (Table 7), that is, the plants did not reach the critical cut limit of 70% of the mean height of the control (Costa et al. 2010). It is worth emphasizing that all herbicide rates resulted in reduced plant height in the range of 30.5 to 45% (Table 7).

Table 7. Mean height of St. Augustine (*Stenotaphrum secundatum*) grass obtained in different times as a result of application of imazapic alone and in tank mix with imazapyr.

Treatment + Rate (g a.i. ha^{-1})	Grass height (cm) DAA\1						
	7	14	21	28	56	119	(%)\2
imazapic 35	4.1^{b}	4.8^{b}	5.2^{b}	5.5^{c}	8.1^{b}	9.5^{b}	37.1
imazapic 70	3.1^{b}	3.9^{b}	4.4^{b}	4.7^{c}	8.8^{b}	10.1^{b}	33.1
imazapic 105	3.5^{b}	4.4^{b}	4.3^{b}	4.6^{c}	7.6^{b}	10.8^{b}	28.5
imazapic 140	3.1^{b}	3.8^{b}	4.0^{b}	4.4^{c}	7.1^{b}	10.1^{b}	33.1
imazapic 175	3.1^{b}	4.4^{b}	4.6^{b}	4.9^{c}	7.0^{b}	10.1^{b}	33.1
imazapic 210	3.3^{b}	4.1^{b}	4.0^{b}	4.4^{c}	6.0^{b}	8.6^{b}	43.0
imazapic+imazapyr 7.9+2.6	3.9^{b}	5.4^{b}	6.5^{b}	6.9^{b}	8.5^{b}	10.1^{b}	33.1
imazapic+imazapyr 15.6+5.2	4.0^{b}	5.1^{b}	5.1^{b}	5.1^{c}	8.6^{b}	9.1^{b}	39.7
imazapic+imazapyr 23.6+7.9	3.6^{b}	4.4^{b}	4.5^{b}	4.5^{c}	7.0^{b}	8.3^{b}	45.0
imazapic+imazapyr 32.5+10.5	3.7^{b}	4.6^{b}	5.0^{b}	5.0^{c}	7.0^{b}	10.5^{b}	30.5
Control	6.5^{a}	8.3^{a}	9.6^{a}	11.9^{a}	14.5^{a}	15.1^{a}	----
F Treatment	4.14**	5.27**	8.38**	18.89**	7.35**	2.74*	----
F Block	3.49*	4.03*	11.82**	7.04**	8.71**	12.59**	----
C.V. (%)	24.48	22.95	21.64	18.59	20.29	21.35	----

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column did not differ statistically from each other by Scott-Knott test at 5% probability level. \1 DAA – days after application; \2 – reduction calculated in comparison with the control.

It can be seen that imazapic applied alone at rates of 70, 105, 175 and 210 g ha^{-1} or combined with imazapyr at the rate of 32.5+10.5 g ha^{-1} did not affect the flower stems height of St. Augustine grass. Regarding the number of inflorescences, it was possible to find a direct and proportional relation with the rate of imazapic applied alone or in combination with imazapyr, so that highest applied dose determined a greater induced production of inflorescences during the study period (Table 8).

Table 8. Mean values of height and number of inflorescences and total dry matter of clippings (TDMC) produced by St. Augustine grass at 119 days after application of the herbicides.

Treatment + Rate (g a.i. ha^{-1})	Inflorescences			TDMC	
	Height (cm)	Number (m^{-2})	(%)\1	g m^{-2}	(%)\1
imazapic 35	10.8^{b}	96.3^{f}	39.3	356.9^{b}	40.2
imazapic 70	14.4^{a}	183.7^{e}	-15.7	335.9^{b}	43.7
imazapic 105	13.9^{a}	251.2^{d}	-58.2	389.9^{b}	34.6
imazapic 140	12.7^{b}	320.0^{b}	-101.5	387.3^{b}	35.1
imazapic 175	14.3^{a}	291.2^{c}	-83.4	378.7^{b}	36.5
imazapic 210	17.0^{a}	373.8^{a}	-135.5	313.2^{b}	47.5
imazapic+imazapyr 7.9+2.6	11.8^{b}	130.0^{f}	18.1	255.6^{b}	57.2
imazapic+imazapyr 15.6+5.2	11.0^{b}	122.5^{f}	22.8	298.7^{b}	49.9
imazapic+imazapyr 23.6+7.9	11.7^{b}	178.8^{e}	-12.6	262.5^{b}	56.0
imazapic+imazapyr 32.5+10.5	14.0^{a}	187.5^{e}	-18.1	354.5^{b}	40.6
Control	15.6^{a}	158.7^{e}	----	596.6^{a}	----
F Treatment	2.76*	47.74**	----	7.00**	----
F Block	3.90*	2.90^{NS}	----	4.10**	----
C.V. (%)	17.82	12.60	----	10.49	----

NS – not significant; ** – significant at 1% probability; * – significant at 5% probability. Means followed by same letter in column do not differ statistically from each other by Scott-Knott test at 5% probability level. \1 – reduction calculated in comparison with the control.

The rates of 105, 140, 175 and 210 g ha^{-1} of the imazapic herbicide applied alone induced the St. Augustine plants to produce a greater quantity of inflorescences compared with the control, resulting in high increases, ranging from 58.2 to 135.5% in the number of inflorescences per m^2 (Table 8).

The rates of 35 g ha^{-1} of imazapic and 7.9+2.6 and 15.6+5.2 g ha^{-1} of imazapic mixed with imazapyr were effective in inhibiting the production of flower stems of St. Augustine plants, with reductions of 39.3, 18.1 and 22.8% in comparison with the control without herbicide application (Table 8).

All treatments evaluated in this study caused significant reductions in the production of total dry matter of clippings of St. Augustine grass, when compared with the control. Such reductions ranged from 34.6 to 57.2% compared with the treatment without herbicides application. It is worth noting that the greatest reductions were observed when the combination of imazapic and imazapyr was applied, irrespective of the dose used (Table 8).

4. Discussion

The visible injury symptoms data observed in this research indicate that Bahiagrass plants are more sensitive to imazapic herbicide applied alone or combined with imazapyr than St. Augustine plants. It could be seen that the visible injury symptoms caused by the herbicide applications on Bahiagrass remained by 119 DAA, while only 30 DAA of the treatments applied on St. Augustine were sufficient for a total recovery of the plants, after which no further toxicity symptoms were recorded. It is important to add that, although the visual injury symptoms for Bahiagrass were observed up to 119 DAA, these levels have remained constant since the assessment of 56 DAA (Table 3 and 6).

It is worth noticing that toxicity levels below 6.5%, as observed in Bahiagrass plants at 119 DAA (Table 3), can be tolerated in lawns, because the use of irrigation or grass colorants may contribute to reduce the period of disappearance of phytotoxicity symptoms. Other alternative can be the application of supplementary doses of nitrogen-based fertilizers, because this element is essential for chlorophyll synthesis and restores the green color of grass plants (Costa et al. 2010; Marchi et al. 2015).

It should be emphasized that the main injury symptoms found in Bahiagrass and St. Augustine grasses consisted of changes in the color of the lawn from green-yellowish to purple. In general, imidazolinone-based herbicide formulations may initially cause chlorosis of young leaves, and the symptoms may progress to an intense purple color of the leaf with subsequent evolution to necrosis of these leaves (Shaner 2014; Piveta et al. 2018).

The considerable reduction in height of Bahiagrass and St. Augustine plants, as can be seen in Tables 4 and 7, can be associated with the fact that imidazolinone herbicides are amino-acid inhibitors, acting mainly in inhibiting acetolactate synthase (ALS), a common enzyme in the biosynthesis of three aliphatic amino acids: valine, leucine and isoleucine. Such inhibition action interrupts the protein synthesis, which interferes with DNA synthesis and cell growth (Marinho et al. 2018).

Additionally, herbicides of this class are easily absorbed by the plant roots and leaves and are quickly translocated to the plant tissues through xylem and phloem, affecting directly the growth and development of susceptible plants (Refatti et al. 2017).

The apparent recovery of the plants height observed at 119 DAA for the herbicide rates of 35 g ha^{-1} of imazapic and 15.6+5.2 g ha^{-1} of imazapic + imazapyr mixture in Bahiagrass (Table 4) and 105 g ha^{-1} of imazapic alone in Bahiagrass (Table 7) can be explained by the fact that nonstructural carbohydrates such as glucose, fructose, sucrose and amides may be stored and used as reserve energy for tolerance to stress and regeneration after the first symptoms of injury (Brighenti et al. 2019).

It is also worth noticing that by 56 DAA, imazapic rates higher than 70 g ha^{-1} applied on Bahiagrass lawns, and all treatments of St. Augustine maintained the lawn height below the maximum limit of 10 cm allowed for lawns located in central road verges and grass strips along highway roadsides (Marchi et al. 2013). Therefore, it can be assumed that application of imazapic herbicide doses have great potential for use as growth regulators for Bahiagrass and St. Augustine grass for a period of 56 days.

The most persistent herbicides have the advantage of providing long-lasting efficiency but may have residual activity and a direct influence on the growth parameters of sensitive plants, depending basically on the soil, environmental conditions, and physicochemical properties of the herbicide (Matte et al. 2018).

With respect to the increases found in the variable number of inflorescences per m^2 of St. Augustine grass, especially after application of rates of 105, 140, 175 and 210 g ha^{-1} of the herbicide applied alone, it can be inferred that inflorescence production was triggered as an adaptive response of the plants to the stress caused by the application of the herbicide rates. As all herbicides operate in crucial plant pathways and processes, either as an inhibiting or stimulating agent, doses of any herbicide can modulate the plant composition, acting mainly in the attempt to improve and increase the seeds propagation, aiming to disseminate a generation free from the stresses caused (Brito et al. 2018).

In general, the results found in this study corroborate the single work found in the literature, which used herbicide of the imidazolinone class in Bahiagrass plant. The study reports that the application of 80 g ha^{-1} of imazethapyr inhibited the vegetative growth of plants by five weeks after application, and the emergence of inflorescences by ten weeks, with injury values ranging from 25 to 30% at the beginning of exposure to the herbicide (Johnson 1990).

5. Conclusions

Applications of imazapic alone or combined with imazapyr, regardless of the rate tested, were effective in reducing plants height, number and height of inflorescences and in the total amount of dry matter of clippings produced by Bahiagrass, and thus can be recommended as growth regulator for lawns grown with this species.

St. Augustine grass plants exhibited less sensitivity to imazapic herbicide applied alone or in tank mix with imazapyr than Bahiagrass plants.

All treatments evaluated in this study provided a satisfactory growth control of St. Augustine grass. However, the use of imazapic as growth regulator caused an increase in the number of inflorescences present in the lawns of this species, thus it is not recommended for areas designed for sports.

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